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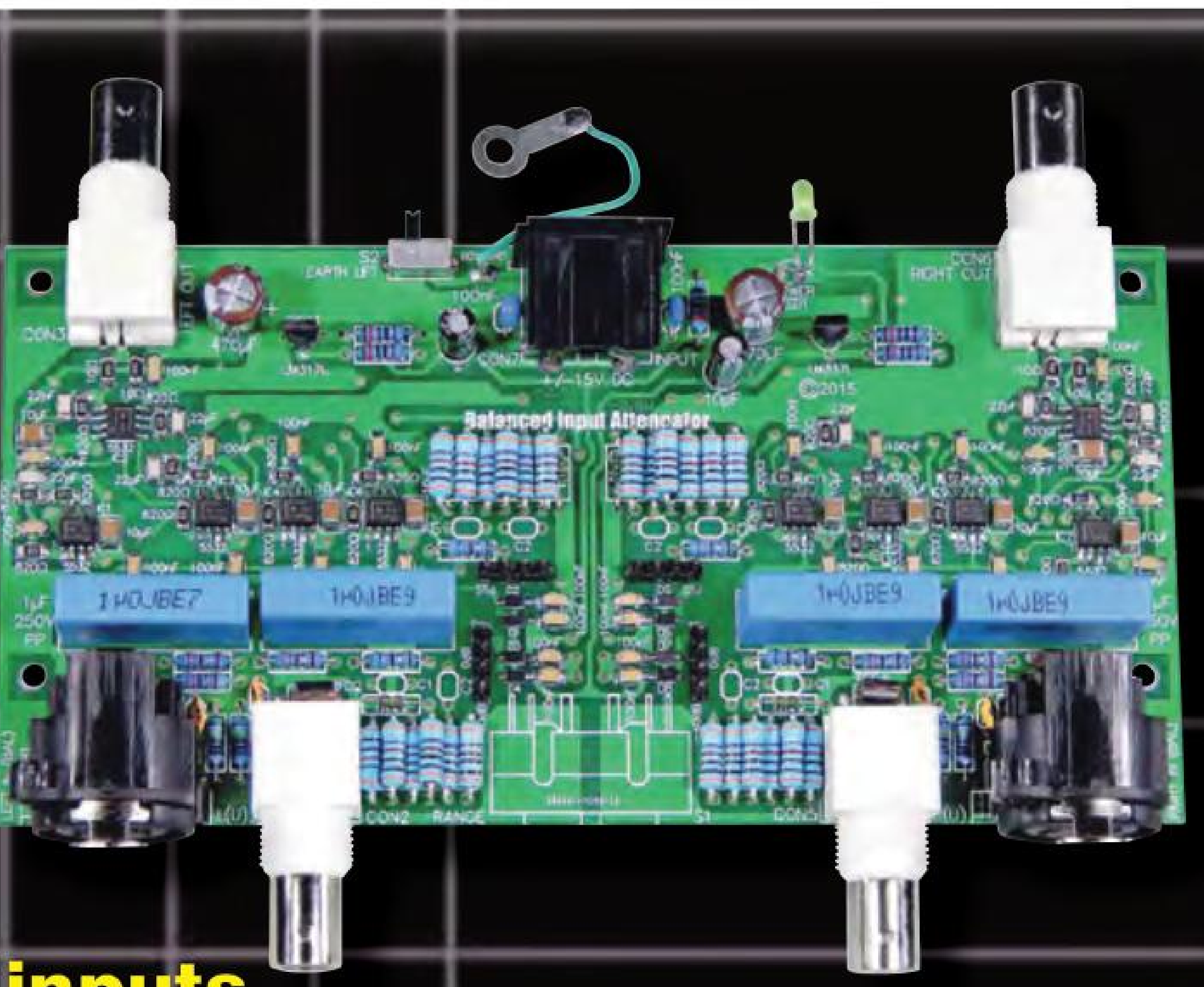

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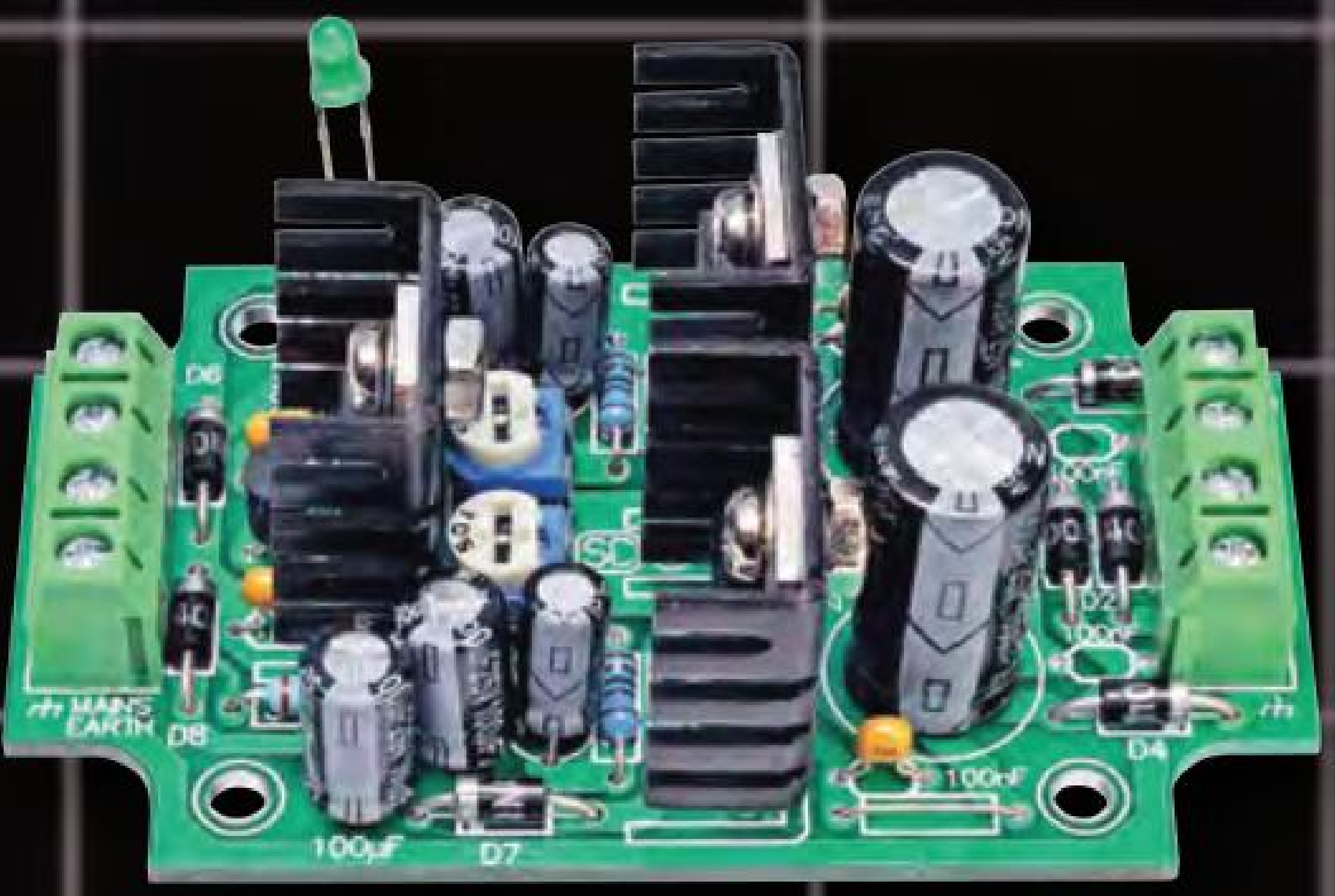

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● PROJECTS ● THEORY ●
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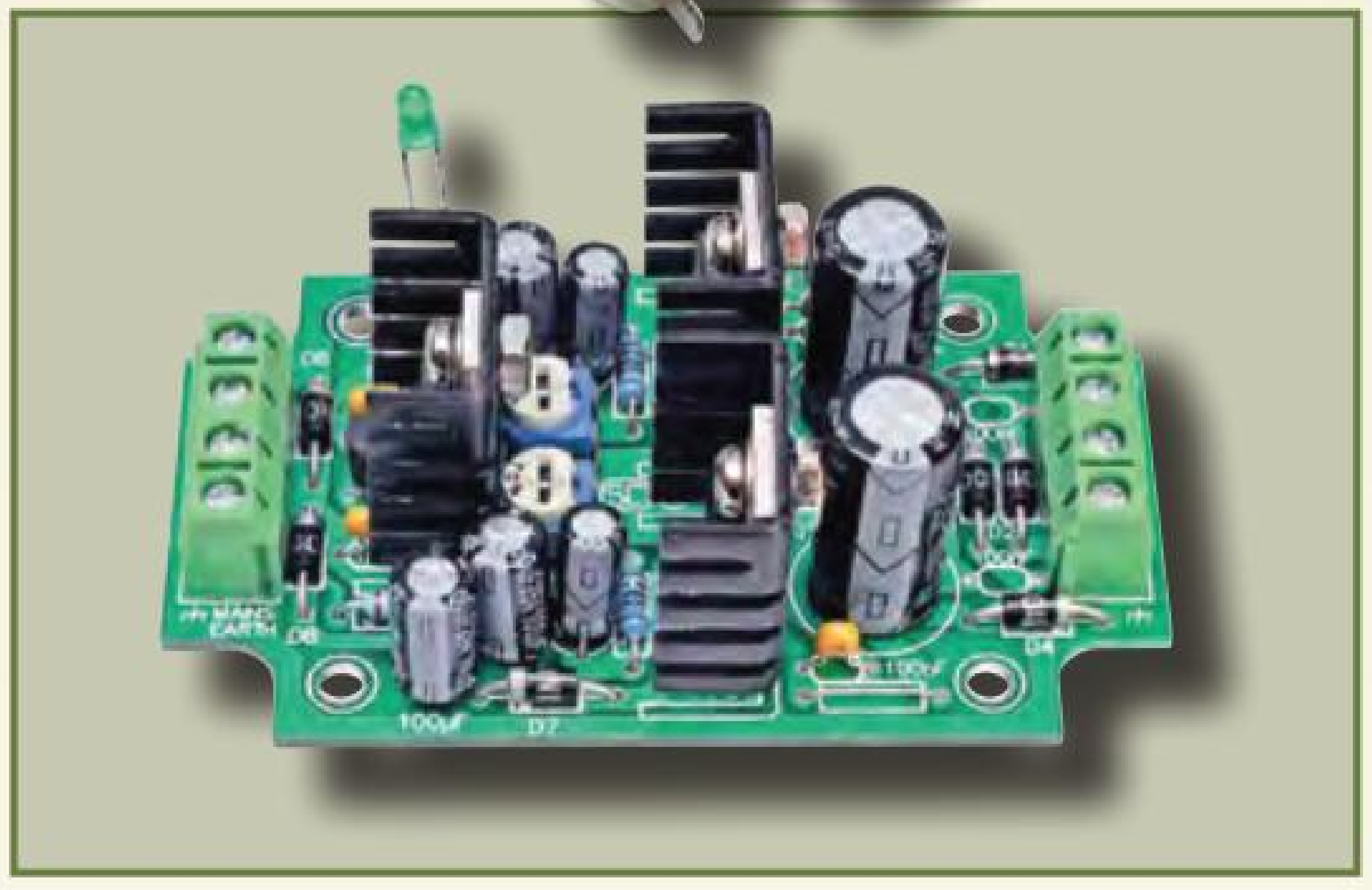

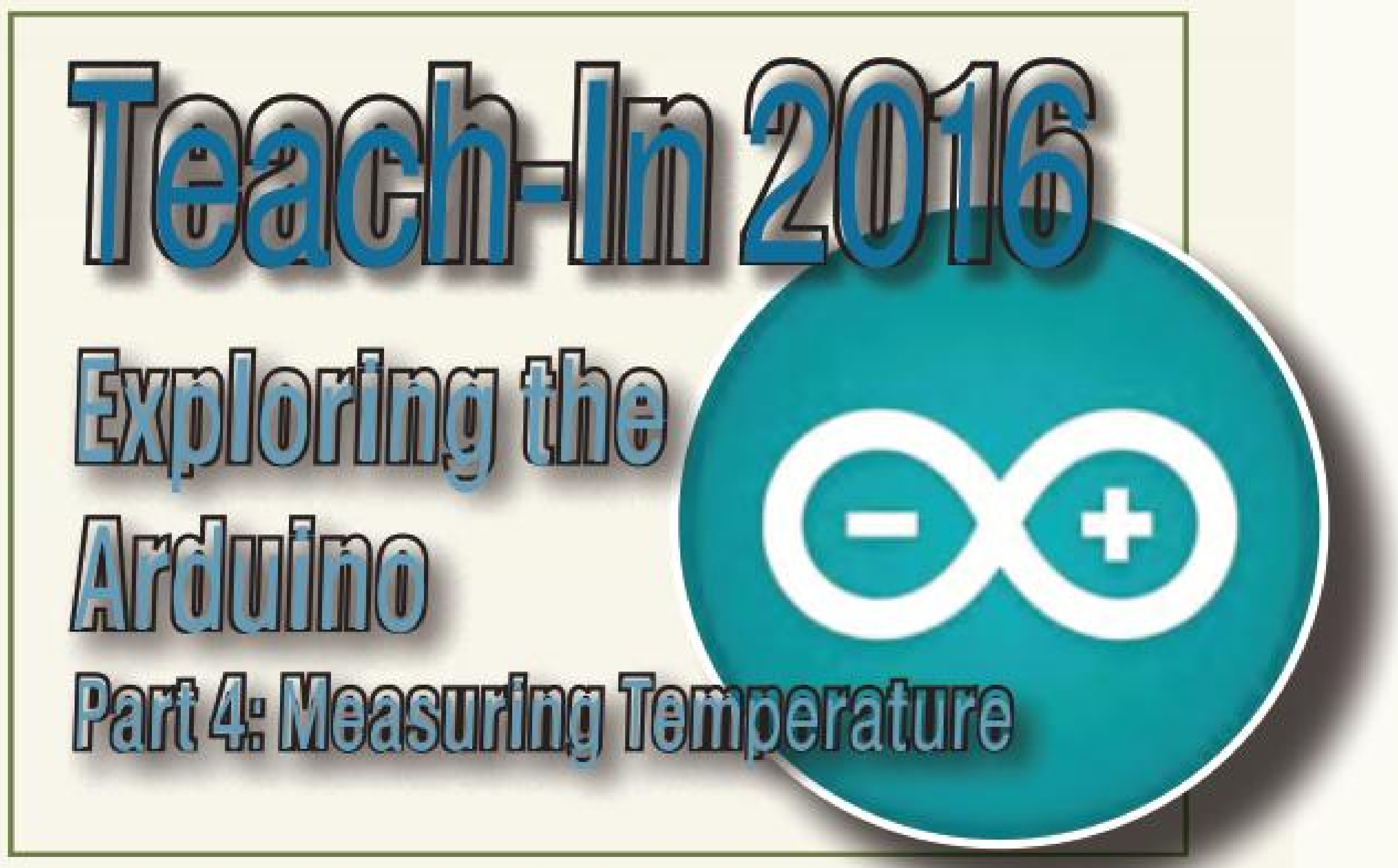

Projects and Circuits

2-CHANNEL BALANCED INPUT ATTENUATOR FOR AUDIO ANALYSERS AND DIGITAL SCOPES 12
by Jim Rowe
Extend the measurement capabilities of low-cost USB test instruments

APPLIANCE EARTH LEAKAGE TESTER 26
by John Clarke
Check the safety of earthed and double-insulated mains-powered equipment

4-OUTPUT UNIVERSAL VOLTAGE REGULATOR 38
by Jim Rowe and Nicholas Vinen
Super-flexible linear regulator board with four outputs: adjustable positive and negative outputs and two fixed positive outputs of 5V and 3.3V

Series and Features

TECHNO TALK by Mark Nelson 11
May madness

TEACH-IN 2016 – EXPLORING THE ARDUINO 46
by Mike and Richard Tooley
Part 4: Measuring temperature

PRACTICALLY SPEAKING by Robert Penfold 54
Switches

NET WORK by Alan Winstanley 57
Power hungry... The power of PUE... Staying vigilant... Insecure feelings

PIC n' MIX by Mike O'Keeffe 60
Choosing and using accelerometers – Part 2

CIRCUIT SURGERY by Ian Bell 64
Oversampling with ADCs

MAX'S COOL BEANS by Max The Magnificent 70
Cunning coding tips and tricks – Part 3... Increasingly sophisticated scenarios... More rings... Mixing control approaches

ELECTRONIC BUILDING BLOCKS by Julian Edgar 76
Variable PWM power module

Regulars and Services

SUBSCRIBE TO *EPE* and save money 4

EDITORIAL 7
Cheap as chips!... Be safe... 'These go to 11'

NEWS – Barry Fox highlights technology's leading edge 8
Plus everyday news from the world of electronics

MICROCHIP READER OFFER 25
EPE Exclusive –Win a Microchip dsPIC33EV 5V CAN-LIN Starter Kit

***EPE* BACK ISSUES CD-ROM** 37

READOUT – Matt Pulzer addresses general points arising 69

CD-ROMS FOR ELECTRONICS 73
A wide range of CD-ROMs for hobbyists, students and engineers

***EPE* PCB SERVICE** 78
PCBs for *EPE* projects

ADVERTISERS INDEX 79

NEXT MONTH! – Highlights of next month's *EPE* 80

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Our June 2016 issue will be published on Thursday 5 May 2016, see page 80 for details.

Readers' Services • Editorial and Advertisement Departments *7*

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Assembled with ZIF socket Order Code: AS3149EZIF - £74.95

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This tutorial project board is all you need to take your first steps into Microchip PIC programming using a PIC16F882 (included). Later you can use it for more advanced programming. It programs all the devices a Microchip PICKIT2® can! You can use the free Microchip tools for the PICKit2™ and the MPLAB® IDE environment.
*Order Code: EDU10 - **£55.96***

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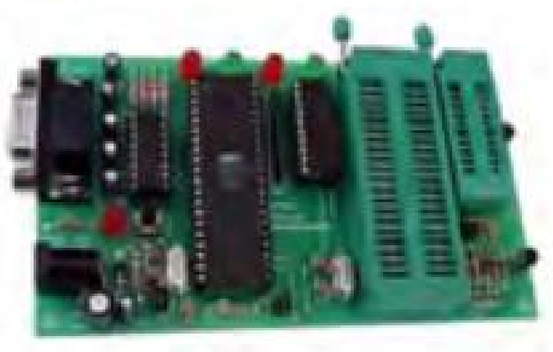

Uses serial port and any standard terminal comms program. 4 LED's display the status. ZIF sockets not included. 16Vdc.
*Kit Order Code: 3123KT - **£28.95***
*Assembled Order Code: AS3123 - **£39.95***

Introduction to PIC Programming

Go from complete beginner to burning a PIC and writing code in no time! Includes 49 page step-by-step PDF Tutorial Manual + Programming Hardware (with LED test section) + Windows Software (Program, Read, Verify & Erase) + a rewritable PIC16F84A. 4 detailed examples provided for you to learn from. PC parallel port. 12Vdc.
*Kit Order Code: 3081KT - **£16.95***
*Assembled Order Code: AS3081 - **£24.95***

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Low cost PIC programmer board supporting a wide range of Microchip® PIC™ microcontrollers. Serial port. Free Windows software.
*Kit Order Code: K8076 - **£29.94***

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*Kit Order Code: K8048 - **£23.94***
*Assembled Order Code: VM111 - **£39.12***

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Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £11.52

USB Experiment Interface Board

5 digital input channels and 8 digital output channels plus two analogue inputs and two analogue outputs with 8 bit resolution.
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*Assembled Order Code: VM110N - **£40.20***

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State-of-the-art high security. 2 channel. Momentary or latching relay output rated to switch up to 240Vac @ 10 Amps. Range up to 40m. Up to 15 Tx's can be learnt by one Rx (kit includes one Tx but more available separately). 3 indicator LEDs. Rx: PCB 88x60mm, supply 9-15Vdc.
*Kit Order Code: 8157KT - **£49.95***
*Assembled Order Code: AS8157 - **£54.95***

Computer Temperature Data Logger

Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
*Kit Order Code: 3145KT - **£19.95***
*Assembled Order Code: AS3145 - **£26.95***
*Additional DS1820 Sensors - **£4.95 each***

Remote Control Via GSM Mobile Phone

Place next to a mobile phone (not included). Allows toggle or autotimer control of 3A mains rated output relay from any location

Most items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix).

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, **Rings** to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
*Kit Order Code: 3140KT - **£79.95***
*Assembled Order Code: AS3140 - **£94.95***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
*Kit Order Code: 3108KT - **£74.95***
*Assembled Order Code: AS3108 - **£89.95***

Infrared RC 12–Channel Relay Board

Control 12 onboard relays with included infrared remote control unit. Toggle or momentary. 15m+ range. 112 x 122mm. Supply: 12Vdc/0.5A
*Kit Order Code: 3142KT - **£64.95***
*Assembled Order Code: AS3142 - **£74.95***

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Detect DTMF tones from tape recorders, receivers, two-way radios, etc using the built-in mic *or* direct from the phone line. Characters are displayed on a 16 character display as they are received and up to 32 numbers can be displayed by scrolling the display. All data written to the LCD is also sent to a serial output for connection to a computer. Supply: 9-12V DC (Order Code PSU375). Main PCB: 55x95mm.
*Kit Order Code: 3153KT - **£37.95***
*Assembled Order Code: AS3153 - **£49.95***

3x5Amp RGB LED Controller with RS232

3 independent high power channels. Preprogrammed or user-editable light sequences. Standalone option and 2-wire serial interface for microcontroller or PC communication with simple command set. Suitable for common anode RGB LED strips, LEDs and incandescent bulbs. 56 x 39 x 20mm. 12A total max. Supply: 12Vdc.
Kit Order Code: 8191KT - £29.95
Assembled Order Code: AS8191 - £39.95

Hot New Products!

Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

4-Channel Serial Port Temperature Monitor & Controller Relay Board

4 channel computer serial port temperature monitor and relay controller. Four inputs for Dallas DS18S20 or DS18B20 digital thermometer sensors (£3.95 each). Four 5A rated relay outputs are independent of sensor channels allowing flexibility to setup the linkage in any way you choose. Simple text string commands for reading temperature and relay control via RS232 using a comms program like Windows HyperTerminal or our free Windows application.
*Kit Order Code: 3190KT - **£84.95***
*Assembled Order Code: AS3190 - **£99.95***

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Feature packed non-volatile 40 second multi-message sound recorder module using a high quality Winbond sound recorder IC. Standalone operation using just six onboard buttons or use onboard SPI interface. Record using built-in microphone or external line in. 8-24Vdc powered. Change a resistor for different recording duration/sound quality. Sampling frequency 4-12 kHz. (120 second version also available)
*Kit Order Code: 3188KT - **£29.95***
*Assembled Order Code: AS3188 - **£37.95***

Bipolar Stepper Motor Chopper Driver

Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
*Kit Order Code: 3187KT - **£39.95***
*Assembled Order Code: AS3187 - **£49.95***

Video Signal Cleaner

Digitally cleans the video signal and removes unwanted distortion in video signal. In addition it stabilises picture quality and luminance fluctuations. You will also benefit from improved picture quality on LCD monitors or projectors.
*Kit Order Code: K8036 - **£24.70***
*Assembled Order Code: VM106 - **£36.53***

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

DC MOTOR SPEED CONTROLLER

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
*Kit Order Code: 3067KT - **£19.95***
*Assembled Order Code: AS3067 - **£27.95***

Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
*Kit Order Code: 3166v2KT - **£23.95***
*Assembled Order Code: AS3166v2 - **£33.95***

Computer Controlled / Standalone Unipolar Stepper Motor Driver

STEPPER DRIVER

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
*Kit Order Code: 3179KT - **£17.95***
*Assembled Order Code: AS3179 - **£24.95***

Computer Controlled Bi-Polar Stepper Motor Driver

Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
*Kit Order Code: 3158KT - **£24.95***
*Assembled Order Code: AS3158 - **£34.95***

AC Motor Speed Controller (600W)

Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
*Kit Order Code: 1074KT - **£15.95***
*Assembled Order Code: AS1074 - **£23.95***

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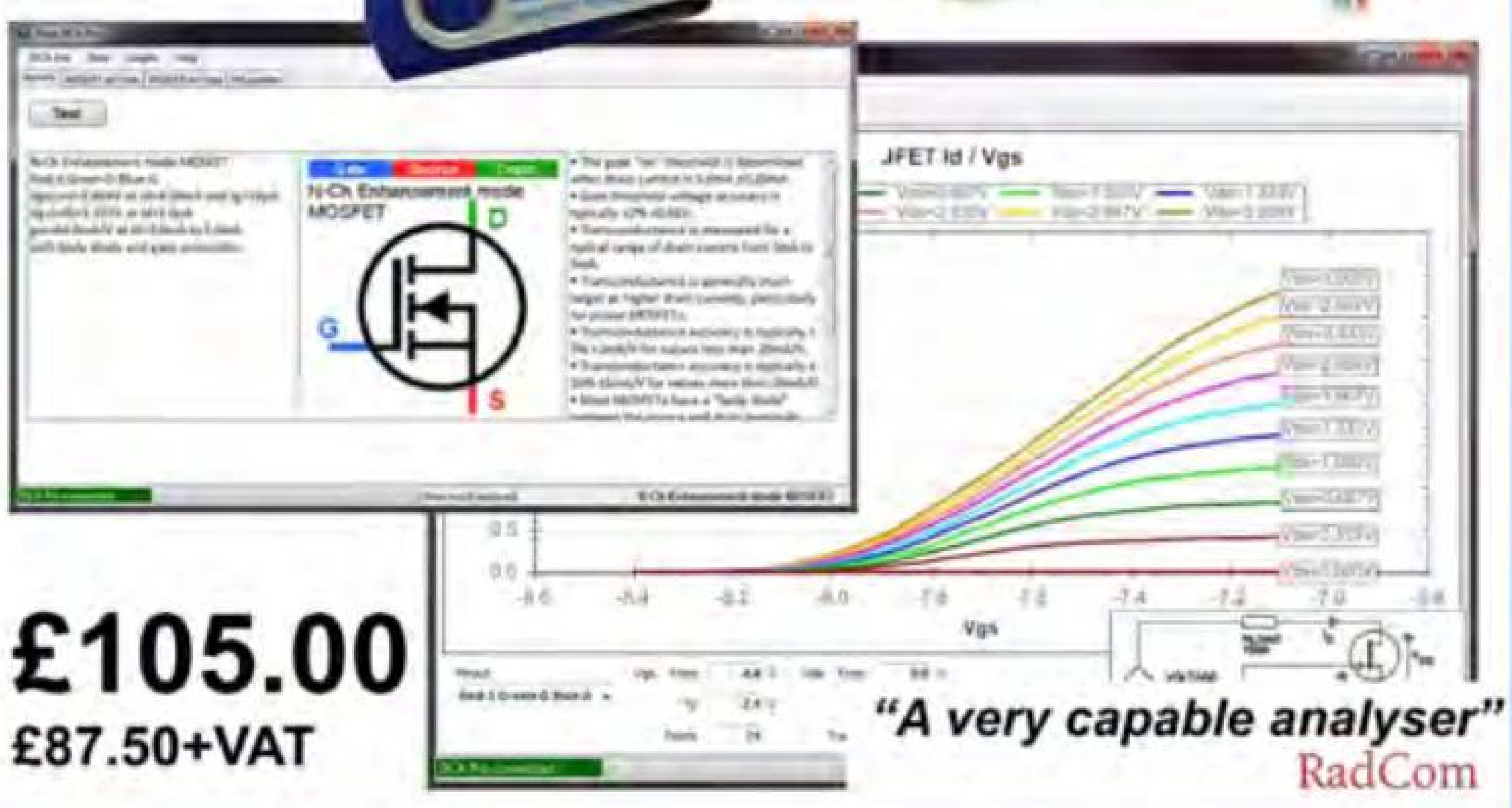
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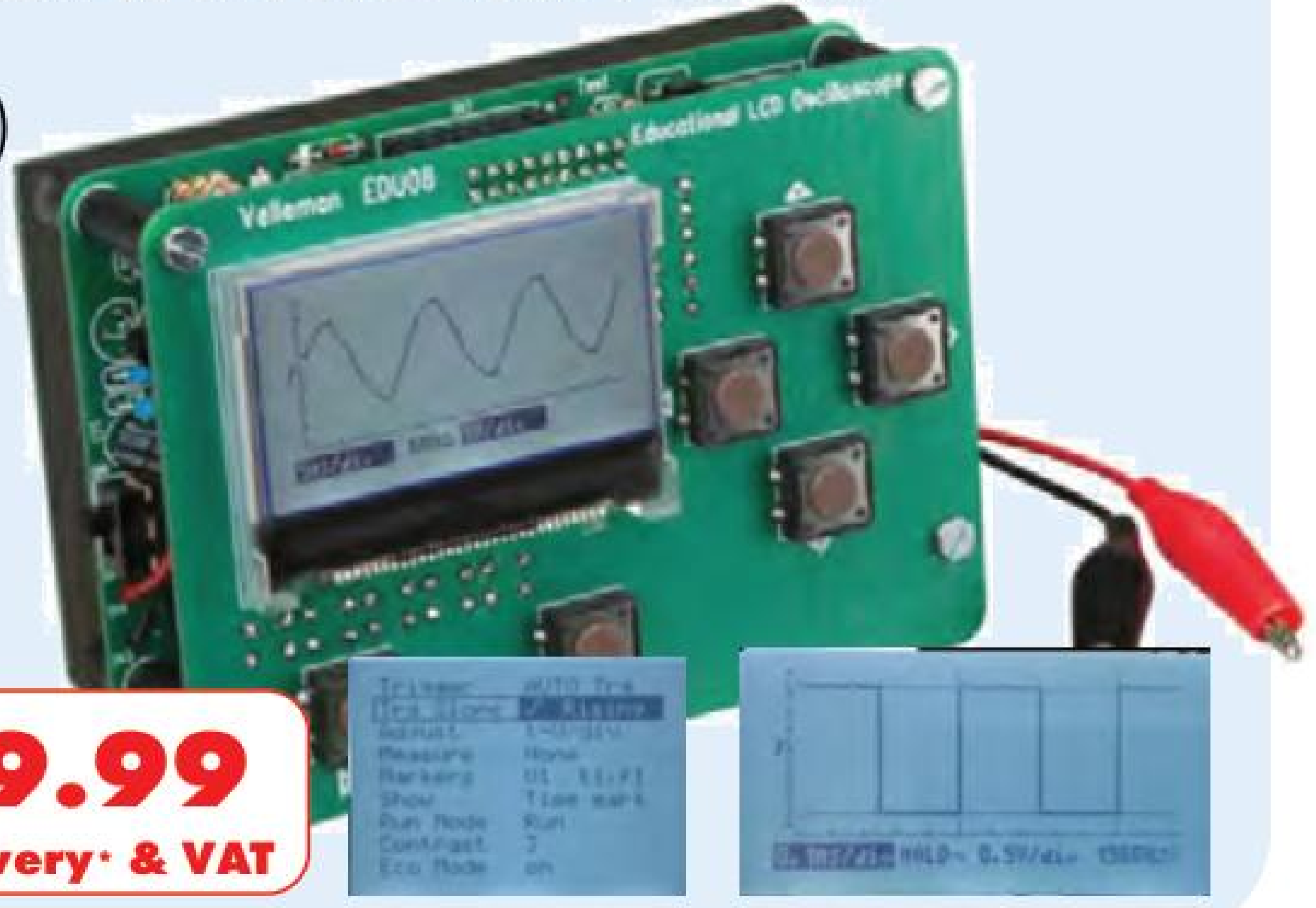

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Editorial Offices:
EVERYDAY PRACTICAL ELECTRONICS
EDITORIAL Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU
Phone: 01202 880299. **Fax:** 01202 843233.
Email: fay.kearn@wimborne.co.uk
Website: www.epemag.com
See notes on **Readers' Technical Enquiries** below – we regret technical enquiries cannot be answered over the telephone.

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113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU
Phone: 01202 880299 **Fax:** 01202 843233
Email: stewart.kearn@wimborne.co.uk

Editor: MATT PULZER
Subscriptions: MARILYN GOLDBERG
General Manager: FAY KEARN
Graphic Design: RYAN HAWKINS
Editorial/Admin: 01202 880299
Advertising and Business Manager: STEWART KEARN 01202 880299
On-line Editor: ALAN WINSTANLEY

Publisher: MIKE KENWARD

READERS' TECHNICAL ENQUIRIES

Email: fay.kearn@wimborne.co.uk

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EPE EVERYDAY PRACTICAL ELECTRONICS

Cheap as chips!

There's an interesting 'tension' between last month's *Techno Talk* article and our ongoing *Electronic Building Blocks* series. Mark pointed out quite correctly that in electronics, as with anything else, 'you get what you pay for'. And yet, even a casual user of eBay or Amazon will be aware that you can buy surprisingly sophisticated and well-made circuits for less than a cup of (admittedly overpriced) high street coffee. Julian Edgar has been writing a very nice column based precisely on these online bargains and I hope you have been enjoying it as much as I have. Quite how the prices are as low as they are, not to mention the free delivery, is as much a mystery to me as anyone else, but they definitely represent new opportunities for hobbyists. I do understand that for some, there is a slight feeling that using such circuits is 'cheating' – where is the pleasure in design and construction? (I suspect some dedicated analogue designers felt equally suspicious when cheap op amps first appeared – 'I've spent years honing my transistor skills and now that's all been replaced with a 741 that anyone can use' – they (possibly) lamented.) I exaggerate, but it may well be that cheap, easy-to-use electronic sub-systems are just the next stage in our hobby, along with the all the other silicon beasts in the electronic zoo.

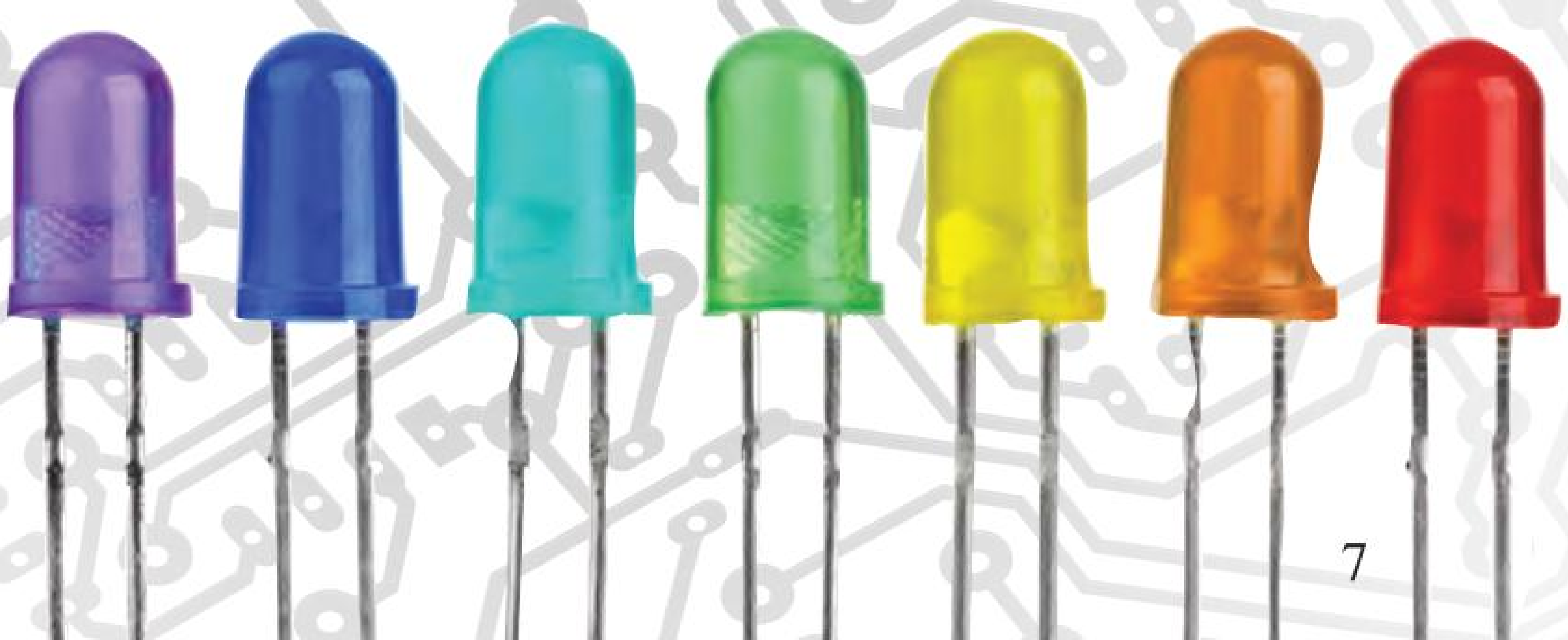
Be safe

This month's *Appliance Earth Leakage Tester* and last month's *Appliance Insulation Tester* are both excellent projects and well worth a thorough read – even if you don't intend to build them. Keeping you safe is a priority for us, so please do bear in mind that these projects are very definitely intended for experienced constructors only. If you have any doubts about your understanding of the project, then do seek out the support, advice and guidance of someone who is competent in ensuring these projects are not only built, but also used correctly and safely.

'These go to 11'

+48v
for RIAA
7
8
9
10
11
12
13
14
15

It's an old joke, but a good one, and space considerations meant I couldn't include Jake Rothman's *Spinal Tap* reference in last month's *Audio Out*. As you can see from the accompanying photograph, his active volume control is not just better, but also louder since the volume can 'go to 15' – see: **https://youtu.be/4xgx4k83zzc** for the original source for this technical breakthrough. (Do readers know any better electronics-themed jokes?!)



NEWS

A roundup of the latest Everyday News from the world of electronics

Filling in the fact gaps – report *by Barry Fox*

The terms 'High Dynamic Range' and 'Wide Colour Gamut' look likely to become more important to TV than '4K resolution'. HDR and WCG are easier to demonstrate – just like colour over black and white. Disney is believed to be keen on releasing Blu-ray discs with HDR and WGC, but in 1080p rather than 4K resolution. The BBC is working on an HD broadcast system with HDR.

But format wars are looming and the industry has done a very poor job of explaining its new technology… herewith the essentials.

Blu-ray update

The new standard for UHD Blu-ray was set last August and runs to 1200 pages. It decrees that video will be compressed using MPEG HEVC/H.265, (high-efficiency video coding) which is the latest MPEG compression system (sometimes incorrectly referred to as MPEG-5). BBC tests have now shown this to be nearly 60% more efficient than the current MPEG-4 AVC/H.264. Coding is in 10-bit digital words, rather than 8-bit words for current Blu-ray.

Modern screens

The new standard gives a choice of EOTF (electro-optical transfer function) and colour coding, to cater for modern screens.

EOTF defines how a TV set turns electric signals (volts) into light on a screen, measured in candelas per square meter (cdm^{-2}) more commonly called 'nits'. 'Ordinary' TVs muster between 100 and 400 nits. New HDR TVs range from around 500 nits up to 1000 nits. OLEDs currently deliver more than a few hundred nits, but have deeper blacks – which is why LG demonstrates in dark corners.

Moving on from a 1930s standard

The existing EOTF standard which gives standard dynamic range contrast is called 'gamma'. It's a non-linear curve that uses less bit depth for bright highlights and more for subtle shadows. But gamma is based on measurements made in the 1930s with CRT screens (although it was not enshrined in an ITU standard, BT.1886, until 2011.)

ULTRA HD™
PREMIUM

Another television standard/marketing strategy for selling TV upgrades, or a welcome attempt to improve quality? – time will tell

The new EOTF ST 2084, recently created by the Society of Motion Picture and Television Engineers, combines non-linear and logarithmic coding for HDR.

The open and mandatory HDR standard, called HDR10, uses ST 2084 and static metadata to match the source material to the display capability. The proprietary and optional HDR systems from Dolby Vision and Philips HDR add dynamic metadata, which adjust the display scene by scene. Dolby Vision needs far more metadata than Philips (up to 25% on top of the video, compared to a few kilobits for Philips).

Current 8-bit Blu-ray discs code colour with the Rec. 709 (also known as BT.709) colour space system which was standardised for widescreen (16:9) high-definition television by international standards body the ITU in 1990. New Rec. 2020 (also known as BT.2020) coding was designed for 10-bit 4K coding.

Colour fidelity

P3, a colour coding system agreed in 2007 for digital cinema by the SMPTE, can reproduce more demanding shades like the red of a London bus, fire engine or Coca Cola label, or the green of an American road sign or Pacific ocean view. Consumer TV sets can't currently handle P3, but future sets will.

In practice, P3 content will be carried by a UHD BD using a BT. 2020 container format. The new 'Ultra HD Premium' marking scheme recently announced by the UHD Alliance requires BT.2020 colour handling with 'more than 90% of P3 colour'. It leaves the HDR system as optional but requires the use of SMPTE ST 2084 EOTF with a combination of peak brightness and black level that is either more than 1000 nits peak brightness and less than 0.05 nits black level, or (to cater for OLEDs) more than 540 nits peak brightness and less than 0.0005 nits black level.

How the industry will test and police the Premium mark with such precision remains to be seen.

EPE EVERYDAY PRACTICAL ELECTRONICS

If you have some breaking news you would like to share with our readers, then please email:
editorial@wimborne.co.uk

Microchip launches free, cloud-based development platform for PICs

Microchip has announced its MPLAB Xpress cloud-based integrated development environment (IDE). This online development platform is an easy way to get started with PIC microcontrollers (MCUs), with zero downloads, sign-in or setup needed to start designing. Microchip's free, cloud-based IDE brings the most popular features of the MPLAB X IDE to Internet-connected PCs, laptops or tablets. MPLAB Xpress offers the industry's most comprehensive feature set, including a library of Microchip-validated code examples, interface to MPLAB Code Configurator (MCC) 3.0 for GUI-based MCU peripheral setup and automatic code generation, integrated MPLAB XC compilers, support for programmer/debugger hardware, and 10GB of secure online storage with a myMicrochip account. Users can easily migrate their projects to the full, downloadable MPLAB X IDE. Additionally, the MPLAB Xpress Community enables developers to share their code, design ideas and knowledge.

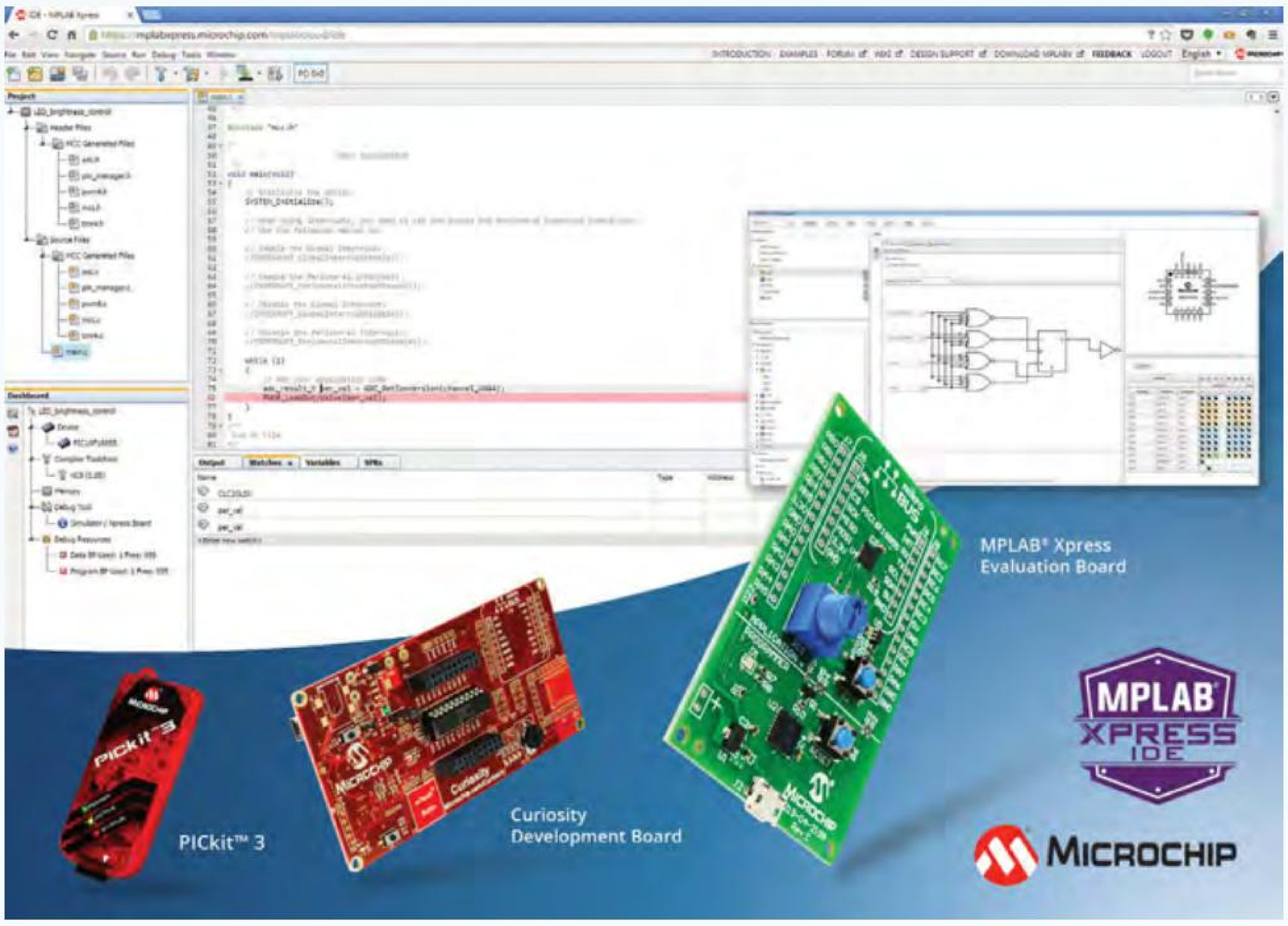
MPLAB Xpress evaluation board

Hardware development

Cloud-based hardware development is supported by connecting any USB-enabled PC, laptop or tablet to tools such as the MPLAB Xpress evaluation board. This development board features an integrated programmer, a PIC16F18855 MCU and a mikroBUS header for system expansion with MikroElektronika's 180+ Click boards. The MPLAB Xpress IDE also supports Microchip's Curiosity Development Board, a cost-effective tool with integrated programmer and debugger, as well as expansion options for add-on boards and external connectivity. Additionally, this online IDE can be used with Microchip's popular PICkit 3 in-circuit debugger/programmer, which provides programming and debugging capabilities for over 1000 PIC MCUs.

The web-based MPLAB Xpress reduces the installation time to zero while enabling users to build an entire application within minutes. Users can open a browser and quickly generate code via the integrated MPLAB Code Configurator, which integrates with MPLAB Xpress: this is a feature which is not available with any other cloud-based IDE. Users can then test that code with the included simulator, compile the code and then programme and debug their target MCU.

For more information, visit: **www.microchip.com/Homepage-021516a**



Microchip's new MPLAB Xpress cloud-based IDE – no downloads, sign-in or setup needed

Hammond Arduino cases

Hammond Electronics has extended its family of design-specific plastic enclosures for housing small form factor development boards with the introduction of the HAMAR, configured for the Arduino LEONARDO, M0 PRO, UNO or YÚN, and the HAMBB.

All models are ready to use with machined or moulded I/O, power and expansion ports to suit the layout of components on the various boards. They are Supplied in translucent blue, grey or black ABS with a satin finish. For more details, visit: **www.hammondmfg.com/1593HAM.htm**

Disease detection with an electronic nose

If a disease produces a scent then it may be detectable using an 'electronic-nose' (e-nose), according to a report in *Chemistry & Industry* magazine (Issue 2, 2016).

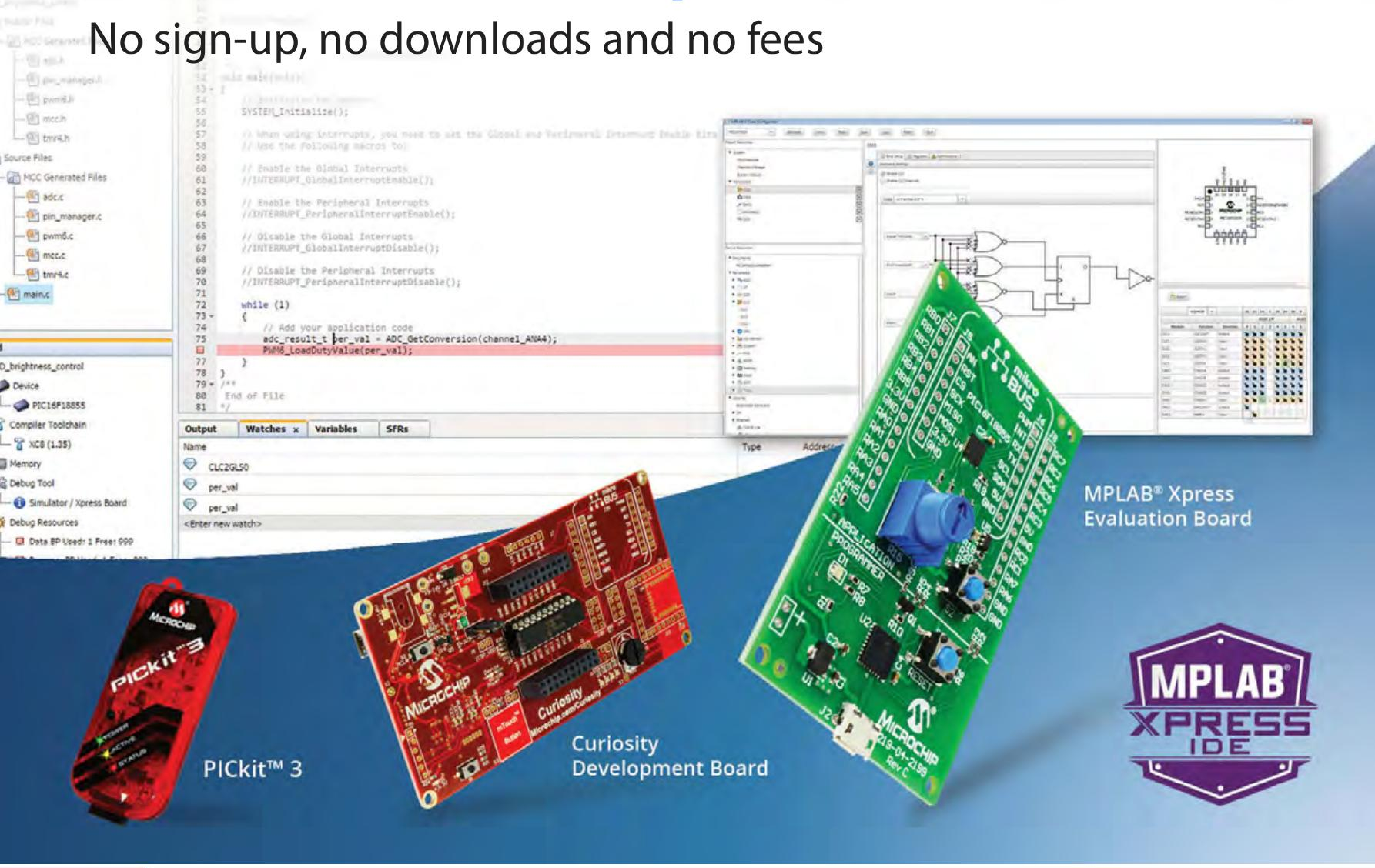
Human metabolic processes produce volatile organic compounds (alcohols and ketones), some of which can be detected on breath, skin, or in urine. When people have certain diseases, their metabolism changes, leading to the production of different VOCs, and this difference is the key to disease detection.

e-noses have up to 30 sensors that react with VOCs on contact and produce a physical change. Software then performs a 'fingerprint analysis', which is then compared with reference patterns in a database. The process is similar to how the human nose works, which recognises an odour signature or pattern of VOCs, rather than the specific compounds.

e-noses are small, fast and can be used at point-of-care, making them a potential game changer in diagnostic medicine. A team headed by Hossam Haick, head of the Laboratory for Nanomaterial-Based Devices at the Israel Institute of Technology has developed a sensor that comprises a flexible, thin film of gold nanoparticles. The result is a cheap, non-invasive test, that can screen for ovarian cancer at its earliest stages and therefore increase survival rates.

Cloud-based development for PIC® MCUs

No sign-up, no downloads and no fees



```
    SYSTEM_Initialize();

    // When using interrupts, you need to set the Global and Peripheral Interrupt Enable Bits
    // Use the following macros to:

    // Enable the Global Interrupts
    //INTERRUPT_GlobalInterruptEnable();

    // Enable the Peripheral Interrupts
    //INTERRUPT_PeripheralInterruptEnable();

    // Disable the Global Interrupts
    //INTERRUPT_GlobalInterruptDisable();

    // Disable the Peripheral Interrupts
    //INTERRUPT_PeripheralInterruptDisable();

    while (1)
    {
        // Add your application code
        adc_result_t per_val = ADC_GetConversion(channel_ANA4);
        PWM6_LoadDutyValue(per_val);
    }
}
/**
 End of File
*/
```

Output
Watches
Variables
SFRs
Name
CLC2GL50
per_val
per_val
<Enter new watch>
Source Files
MCC Generated Files
adc.c
pin_manager.c
pwm6.c
mcc.c
tmr4.c
main.c
Device
PIC16F18855
Compiler Toolchain
XC8 (1.35)
Memory
Debug Tool
Simulator / Xpress Board
Debug Resources
Data BP Used: 1 Free: 999
MPLAB® Xpress Evaluation Board
Curiosity Development Board
PICkit™ 3
MPLAB® XPRESS IDE

Microchip's MPLAB® Xpress Cloud-based Integrated Development Environment (IDE) is the easiest way to start your design with PIC® microcontrollers. Using the industry's most comprehensive feature set you can build your design in minutes and automatically generate code online with the MPLAB Code Configurator 3.0.

Browser-based access to the most popular tools from the award-winning MPLAB X IDE also includes code simulation, as well as programming and debugging of your target MCU. Plus a rich online community provides a forum for sharing ideas and knowledge.

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TechnoTalk

May madness

Mark Nelson

This month, we were going to reveal the meaning of life and explain the relationship of gravitational waves to hobby electronics in simple terms – but those subjects have already been done to death. So instead, Mark Nelson discusses matters that are far more cogent.

KNOWLEDGE IS A MARVELLOUS thing – but only if you have wisdom as well. If you possess both, you'll be aware that knowledge is *knowing* that a tomato is a fruit, but wisdom is *not* putting it in a fruit salad. You'll also be aware that a 'jack plug socket' is simply a jack. But why is it a jack and how far back does this perverse term go?

History lesson

If I said back to at least 1643, you might not believe me, but it's true, in a roundabout way. In the electronic context, the word 'jack' is a contraction of 'spring-jack', which itself can be traced back to 1879 in British patent No. 4903. This document describes a piece of telephone apparatus and states that 'a local circuit, distinct from the line and normally open, is completed when a connecting plug is inserted in a 'block' or spring-jack.' The 1913 edition of *Webster's Dictionary* defines the word 'jack' in telegraphy and telephony as: 'a terminal consisting of a spring-clip, by means of which instruments can be expeditiously introduced into the circuit. In telephones, such terminals are sometimes used at exchanges for allowing the lines of different subscribers to be quickly connected. The connection is made by means of a wire cord on the ends of which are metallic wedges covered on one side with insulating material. These wedges, called jack-knives or simply jacks, are inserted into the terminals of the lines to be connected. Also called spring-jack.'

So the word 'jack' in this context derives from 'jack knife', which the website **dictionary.com** defines as: '1705-15, Americanism; jack (cf. jockteleg) + knife'. And looking up 'jockteleg' on the same website we find it dates back to: '1665-75; orig. Scots; first attested as jackteleg, perhaps with Jack or Jock and leg, alluding to knife handles carved in the form of a leg'. *The Dictionary of the Scots Language* confirms this, stating 'a clasp-knife, may contain an allusion to the leg-like shape of the hafts of early knives of this kind'. It also dates use of the word back to 1643. I knew you'd want to know.

Beam benders

The same hinged or crooked leg term was used (in translation) by the Germans to name their *Knickebein* radio target location system during World War Two. Narrow radio beams from two widely separated transmitters crossed at an obtuse angle to identify strategic targets for bombing. Special radio receivers on board the German aircraft indicated when the bombs should be released. In retaliation, a team of British Air Ministry electronic countermeasures technicians (known as the 'Beam Benders') devised a system that appeared to bend the beam away from the target (**https://en.wikipedia.org/wiki/Battle_of_the_Beams**).

A 'jack' plug from the seventeenth century... or possibly later.

DIY beam manipulation

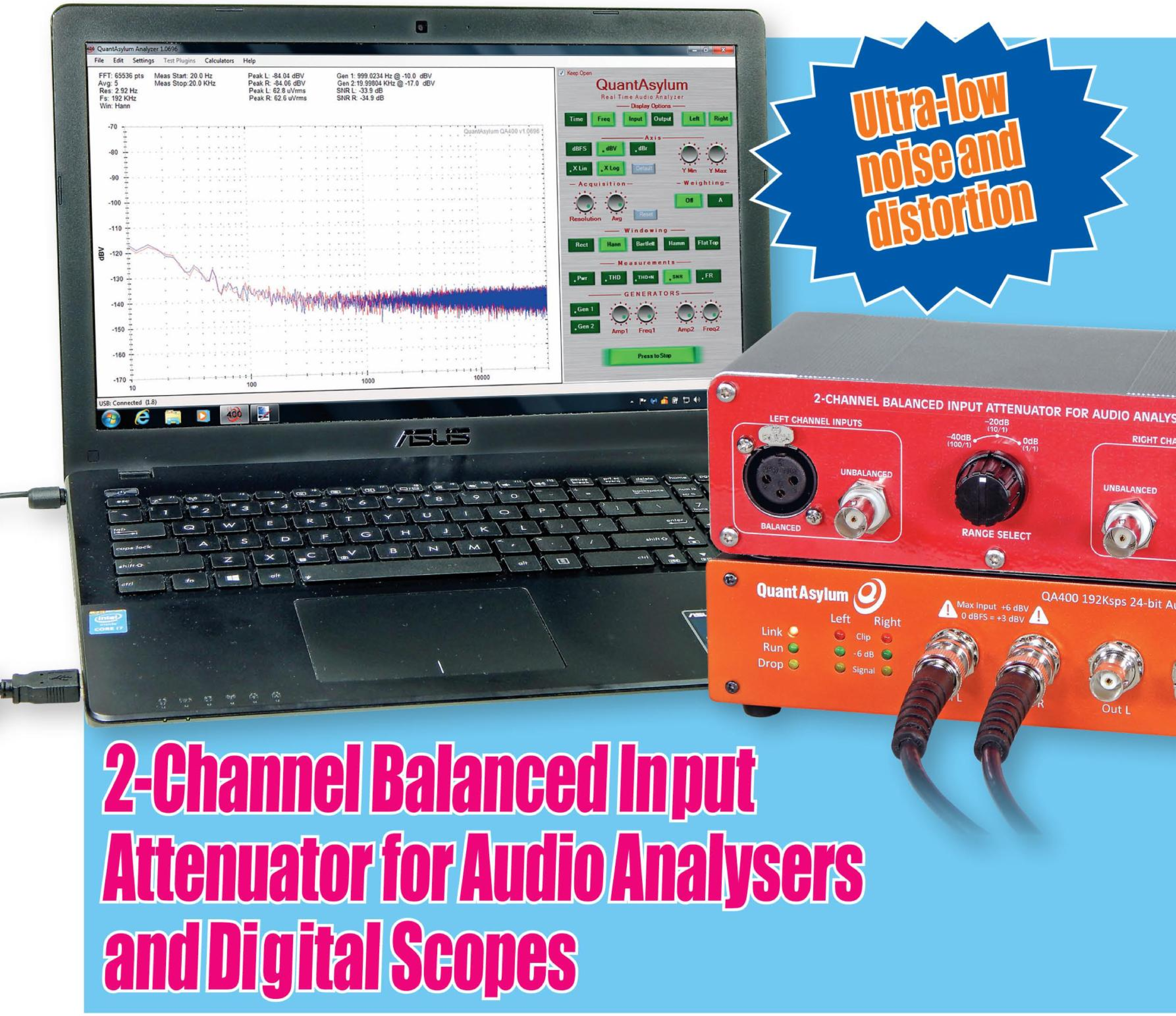
One of my correspondents recently managed to turn defeat into success in his own personal radar war, and you might be interested to learn about his beam-bending pursuits. For some bizarre reason, passers-by mistook his front garden for a dossing area or public convenience, activities that he really did not wish to encourage. On **eBay.co.uk** he discovered an extremely low-priced 'radar' – a combined lamp bulb and motion sensor (eBay item number 201308497108). Effectively an LED bulb with a built-in PIR sensor operating on any voltage between 85V and 265V AC, this illuminates whenever anybody walks past, making any unwished-for nocturnal activities plain for all to see. I'll let him take up the story. 'The problem was the bulbs spread out a 'beam' that was so wide that pedestrians on the street outside were triggering it every minute or so. If they did, the light comes on for thirty seconds and then cuts out. I had a brainwave last night, and removed the diffusion dome of the light, and then used insulating tape to place a two-inch-deep steel pastry-cutter standing out on the neck of the light. This acted so as to 'focus' and narrow the beam by about 50 per cent. It now works a treat and is triggered only when people pass or rather 'cut' through the beam. I am rather pleased with this solution.'

As solutions go, it's both ingenious and economical, which would make it a natural for **www.Instructables.com**. If you haven't seen this website yet, you really should, as it nicely sums up the spirit of 'Everyday Practical Electronics'!

Follow on: copper-bottomed confidence trick

In April's column I wrote about the downside of using cheap copper-coated steel (CCS) and copper-coated aluminium (CCA) wire for data and telephone cabling. A reader wrote in to mention an additional 'gotcha' when you use this pernicious stuff. He says: 'I don't think even those in the business of selling the stuff understand its shortcomings. Sure, it looks like telephone or data cable, so it must be OK. But it's not, and there's another serious negative point that deserves wider attention.

'IDC (insulation displacement contact) terminations have all but replaced the old screw terminals. They're good, but not foolproof, and work properly only if you use the right materials. That's because they rely on the blades cutting into the conductors to make a sound and lasting joint. In the case of CCS, the cable conductor material is simply too hard. Therefore the blades will sit on the surface, rather than cut in and make proper contact with the conductor. Moreover, as we have seen when BT used CCS for overhead wires (for strength), the terminations are a weakness, due to rusting where the conductors are open to the atmosphere. One of my old workmates already has experience of CCS. When he left BT, he became the in-house comms man at an NHS hospital. He says the cabling contractors used CCS at the hospital. Disgraceful. Just to save a few quid. There oughta be a law against it!'


QuantAsylum Analyzer 1.0696
File Edit Settings Test Plugins Calculators Help
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2-CHANNEL BALANCED INPUT ATTENUATOR FOR AUDIO ANALYS
LEFT CHANNEL INPUTS
BALANCED
UNBALANCED
RANGE SELECT
−20dB (10/1)
−40dB (100/1)
0dB (1/1)
RIGHT CHA
Quant Asylum
QA400 192Ksps 24-bit A
Max Input +6 dBV
0 dBFS = +3 dBV
Link
Run
Drop
Left
Right
Clip
-6 dB
Signal
Out L

Ultra-low noise and distortion

2-Channel Balanced Input Attenuator for Audio Analysers and Digital Scopes

This project is designed to extend the measurement capabilities of low-cost USB test instruments like the QA400 Stereo Audio Analyser or USB DSOs. It provides balanced/differential inputs for each channel in addition to unbalanced inputs, combined with three attenuation/measurement ranges: 1:1, 10:1 and 100:1.

INSTRUMENTS, SUCH AS THE QuantAsylum QA400 low-cost USB Stereo Audio Analyser possess impressive performance capabilities. However, in some areas it has disappointing limitations, which restricts its practical applications.

In particular, two drawbacks stand out. First, it has a maximum input level of only 1.41VRMS/4.00V peak-peak for both input channels. That makes it fairly useless for a lot measurements; you would have to use external input attenuators if the QA400 were to be used for making useful measurements on HiFi, guitar and PA amplifiers.

Second, the QA400 only provides unbalanced inputs, whereas you need balanced inputs in order to efficiently test professional audio equipment. Balanced or differential inputs also

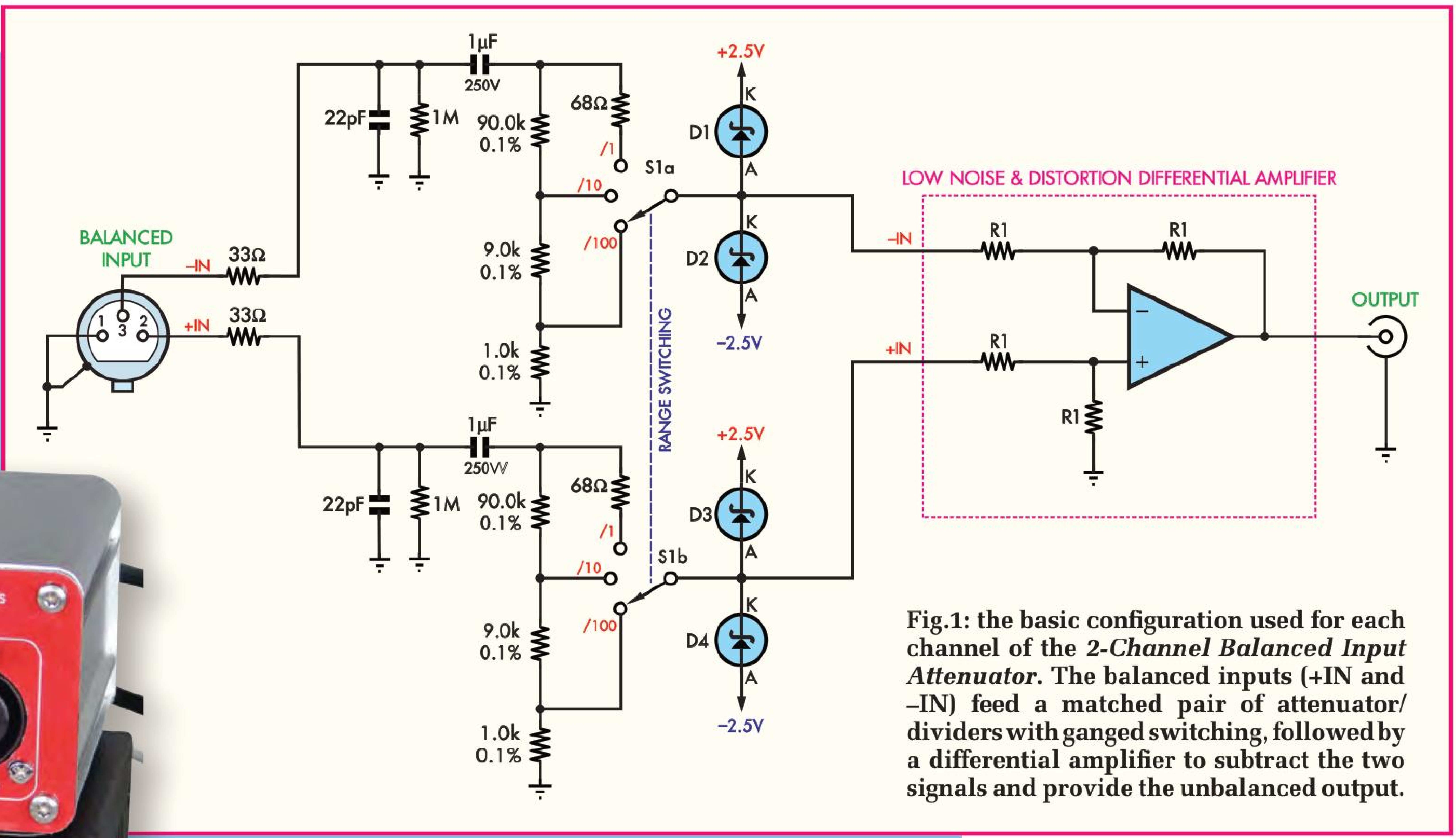


Fig.1: the basic configuration used for each channel of the *2-Channel Balanced Input Attenuator*. The balanced inputs (+IN and –IN) feed a matched pair of attenuator/dividers with ganged switching, followed by a differential amplifier to subtract the two signals and provide the unbalanced output.

ERS & DSOs
NNEL INPUTS
BALANCED
dio Analyzer
Out R

Left: the *2-Channel Balanced Input Attenuator* is built into a case that's almost exactly the same size as QuantAsylum's QA400 Stereo Audio Analyser, so that the two can be stacked together.

By JIM ROWE

allow instruments like the QA400 to be used to make accurate measurements on signals at the output of bridge-mode analogue amplifiers or class-D digital amplifiers where neither side of the outputs is earthed.

As a result, we realised that the applications of instruments like the QA400 could be greatly expanded by designing an 'outboard' 2-channel input attenuator to allow measurements at significantly higher audio power levels, combined with balanced/differential inputs for each channel in addition to unbalanced inputs.

Such a project is not restricted to enhancing audio analysers like the QA400. Many, if not most, low-cost USB DSOs have similar limitations, and would therefore benefit in the same way. And we should also mention the *Digital Audio Millivoltmeter* described in the March 2011 issue of *EPE*, which had similar limitations.

Finally, we should also mention that this project would make a useful addition to any oscilloscope when you need differential inputs, albeit its bandwidth does limit its use to signals with harmonics no higher than 750kHz (eg, square-wave signals to about 75kHz) – see specifications panel

So you can see the design concept is quite straightforward, but producing a design which was 'good enough' turned out to be a real challenge. This was largely because of the need to introduce as little additional noise and distortion as possible, because this would detract from the excellent performance of the QA400.

Basic configuration

Fig.1 shows the basic configuration for one channel: balanced inputs (+IN and –IN) feeding a matched pair of attenuator/dividers with ganged switching, followed by a differential amplifier to subtract the two signals and provide the unbalanced output.

Don't worry about the circuitry shown inside the differential amplifier at present – we'll move onto that shortly. Just note that the purpose of Schottky diode pairs D1/D2 and D3/D4 at each input of the differential amplifier are to limit the signal levels to within windows between ±2.7V, to protect both the differential amplifier and the input of a following instrument, such as the QA400.

The 68Ω resistors in series with the '/1' position of switches S1a and S1b are there to limit the current in these diodes, together with the 33Ω resistors in series with each input.

Ideally, we'd like to make these series resistors somewhat larger than 101Ω (= 33Ω + 68Ω), because the diodes we're using for D1-D4 have a

2-CHANNEL BALANCED INPUT ATTENUATOR FOR AUDIO ANALYSERS & DSOs
LEFT CHANNEL INPUTS
UNBALANCED
BALANCED
–20dB
(10/1)
–40dB
(100/1)
0dB
(1/1)
RANGE SELECT
RIGHT CHANNEL INPUTS
UNBALANCED
BALANCED
PUSH

The front panel carries two 3-pin XLR sockets for the balanced inputs, two BNC sockets for unbalanced inputs and the range selector switch.

fairly low maximum current rating. However, we are forced to compromise at the values shown because these resistors are directly in series with the inputs when S1 is switched to the 1:1 range. This means that their thermal (Johnson) noise is added directly to the input signals, thus degrading the attenuator's noise performance.

As set out later in an accompanying panel, the thermal noise generated in a resistor is directly proportional to the square root of its resistance multiplied by the absolute temperature and the bandwidth being used. This means that if we were to increase the value of the input series resistors to, say, 1kΩ, the RMS thermal noise voltage at each input of the differential amplifier would rise from 186.79nV (–134.6dBV) to 587.6nV (–124.6dBV), measured at 25°C and over the band from 20Hz to 21.0kHz.

In other words, the noise level at each input would be degraded by 10dB.

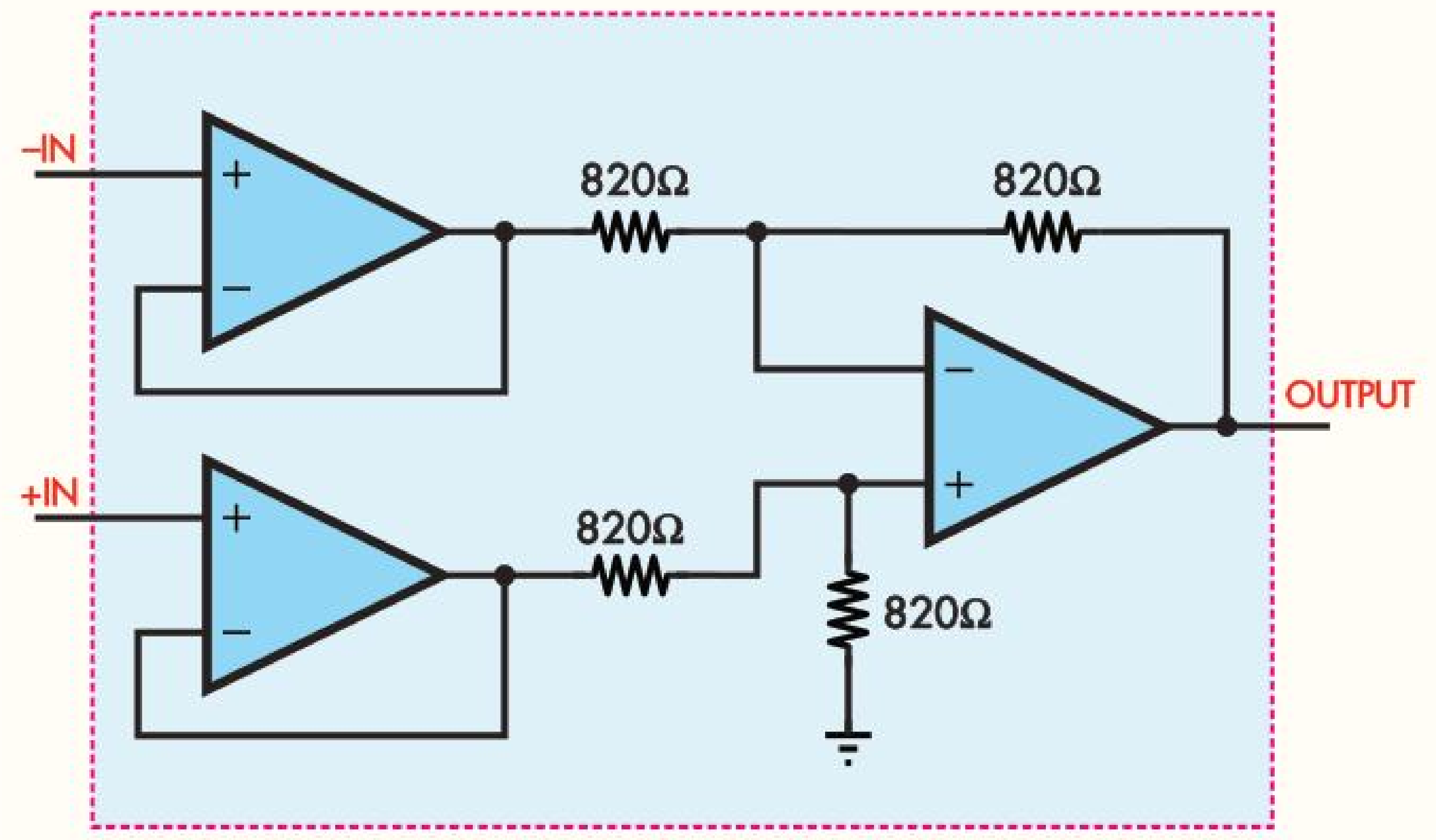


Fig.2: to achieve better performance in terms of noise and distortion, this is the configuration used for the output differential amplifier. In practice, an array of four of these are used in parallel.

Note that since the two sources of thermal noise are not correlated, the output noise level of the differential amplifier would be degraded by a further 6dB, even if the amplifier itself was totally noiseless. So with the resistor values shown in Fig.1, the RMS output noise level will always be above 373nV (–128.6dBV), while if the input resistors were increased to 1kΩ it would always be above 1.175μV (–118.6dBV).

Those 33Ω resistors in series with each input are mainly to form low-pass filters in conjunction with the 22pF shunt capacitors, to improve the RFI/EMI rejection of the overall circuit. You'll find that in the final circuit we have also fitted small inductors in series with the 33Ω resistors, to further improve EMI rejection.

The 1μF coupling capacitors on each input reject any DC that may be present, while having minimal effect on the low frequency response. And the 1MΩ shunt resistors on the input side of the capacitors are to bleed away any charge remaining on those capacitors when the inputs are disconnected from a source of DC.

Finding the right amplifier(s)

Let us now consider the crucial aspect of the project's design: how to achieve the best noise and distortion performance from the output differential amplifier section (shown inside the dashed rectangle of Fig.1). In other words, which is the best op amp to use and what is the best configuration to use it in?

We began by searching through all the data we could find on low-noise, low-distortion op amps. Initially, this led us to the Analog Devices AD797, a device with particularly impressive noise and distortion specs: 1.2nV/√(Hz) maximum input voltage noise density between about 80Hz and beyond 10MHz, coupled with a typical THD figure of –120dB at 20kHz.

However, when we looked closely at the performance of the AD797 when used as a differential amplifier, we found that its noise performance wasn't as good: the output voltage noise spectral density jumped up to around 9nV/√(Hz), giving an RMS noise output of close to 1.3μV (–117.5dBV) over the 20Hz – 21kHz audio bandwidth.

Even to achieve this level of performance, the resistor values shown as R1 in Fig.1 had to be lowered to 1kΩ, making it very difficult to achieve a total input resistance of more than 2kΩ on the 1:1 range of S1. This obviously wasn't high enough, suggesting that voltage follower/buffers were going to be needed ahead of the differential amplifier.

There was one more drawback regarding the AD797 – it is quite pricey and since at least two of these were going to be needed (one per channel) we looked for an alternative approach. Eventually, we found such an approach in the book *Small Signal Audio Design* (Focal Press/Elsevier, Second Edition 2015; ISBN 978-0-415-70973-6), by renowned audio engineer Douglas Self. In chapter 18 of this book, starting on page 483, Douglas Self gives a great deal of useful information on the design of low-noise balanced input stages.

He explains why the standard differential amplifier configuration like that shown in Fig.1 cannot achieve an output noise level as low as an unbalanced input stage using the same op amp, unless the resistor values are reduced to a level that gives an unacceptably low input resistance – regardless of the actual op amp being used.

He then explains that the best approach is to use the configuration shown in Fig.2, where the differential amplifier is preceded by a pair of op amps connected as voltage follower buffers. This allows the four resistors around the differential amplifier to be reduced to a value giving an acceptable noise level, while the voltage followers provide a unity-gain impedance step-up for the two inputs.

At the same time, the input buffers don't degrade the CMRR (common-mode rejection ratio), because this is still defined by the tolerance of the 820Ω resistors around the differential amplifier and also by its bandwidth.

Self then goes on to analyse the performance of this configuration and explain why the resistor values can't really be reduced below 820Ω, without degrading the distortion performance. (This is mainly because of the current drive capability of the input buffers and also of the differential amplifier itself.)

He explains that by using 820Ω resistors with the well-known (and much lower cost) 5532 low-noise op amps in all three positions, the noise output of the Fig.2 configuration can be lowered to –112.4dBV. This is about 7.3dB above the level that could be achieved with a single AD797 differential amp, so it's still not good enough.

Main features and specifications

Description: a 2-channel balanced input attenuator with low noise and distortion suitable for extending the measurement range of audio analysers and digital oscilloscopes (both self-contained and USB linked). It provides a choice of either balanced/differential or unbalanced inputs for either or both channels, plus the ability to quickly select one of three measurement ranges.

Input resistance (DC): 1MΩ

Input impedance (AC): 100kΩ shunted by approximately 25pF

Maximum input voltage: 10V to ground, 20V peak-to-peak/7V RMS differential on 0dB range; 100V to ground, 200V peak-to-peak/70V RMS differential on other ranges

Output clipping level: approximately 4V peak-to-peak (1.4V RMS sinewave)

Attenuation/measurement ranges: 1:1 (0dB); 10:1 (–20dB); 100:1 (–40dB)

Frequency response (both channels):
0dB range: ±0.1dB from 11Hz – 35kHz, –3dB at 750kHz
–20dB range: ±0.1dB from 11Hz – 20kHz, –0.5dB at 35kHz, –3dB at 1.5MHz
–40dB range: ±0.1dB from 11Hz – 10kHz, –0.3dB at 20kHz, –3dB at 4.25MHz
(Note: these figures apply for both balanced and unbalanced inputs)

Gain/attenuation accuracy: ±2% (±0.2dB)

Signal-to-noise Ratio (20Hz-80kHz measurement bandwidth):
0dB range: 114dB with respect to 1.4V RMS input/output
–20dB range: 108dB with respect to 14V RMS Input/1.4V RMS output
–40dB range: 98dB with respect to 26.6V RMS input/266mV RMS output

Output noise level:
0dB range: –136dBV (158nV) 400Hz – 40kHz; –113dBV (2.24μV) at 15Hz
–20dB range: –138dBV (126nV) 400Hz – 40kHz; –116dBV (1.6μV) at 15Hz
–40dB range: –138dBV (126nV) 200Hz – 40kHz; –116dBV (1.6μV) at 15Hz

Total Harmonic Distortion (20Hz-80kHz measurement bandwidth):
0dB range: <0.0005%, 20Hz – 20kHz
–20dB range: <0.0005% 20Hz – 2kHz, <0.0025% 2kHz-20kHz
–40dB range: <0.002% 20Hz – 25Hz, <0.0015% 25Hz-2kHz

Channel separation with a 1V RMS signal (*QA400 Analyser alone: 100dB*)**:**
0dB range: >100dB, 20Hz – 20kHz
–20dB range: >80dB, 20Hz – 1kHz; >60dB, 1kHz-20kHz
–40dB range: >95dB, 20Hz – 1kHz; >70dB, 1kHz-20kHz

Common mode rejection ratio:
0dB range: >60dB, 20Hz – 20kHz; typically >80dB
–20dB range: >50dB, 20Hz – 20kHz; typically >65dB at 1kHz
–40dB range: >40dB, 20Hz – 20kHz

Power supply: runs from an external ±15V DC supply, with a current drain of approximately 200mA

Multiple op amps and noise cancellation

As Douglas Self moves on to explain, there *is* a fairly easy way to improve noise performance quite significantly: by using an array of identical differential amplifiers driven by an array of input buffers. So that's what we are using in this project, with four differential amplifiers connected in parallel, driven by four pairs of unity-gain input buffers.

The thinking behind this is that connecting two identical amplifiers in parallel causes the noise generated in each to mostly cancel, because they are not correlated. This happens each time the number of amplifiers is doubled, so that by using four identical differential amplifiers in parallel, we can achieve a 6dB drop in the overall noise output. Similarly, we can achieve a further 3dB drop in noise output by using a separate pair of input buffers for each differential amplifier, to achieve better buffer noise cancellation.

The end result of moving to this eight-buffers-driving-four-differential-amplifiers configuration gives a total improvement in noise level of about 9dB – so even if we use 5532 op amps throughout, the noise output level drops to –119.2dBV. This is a couple of dB better than we could achieve with a single AD797, even if it were preceded by a couple of AD797s as input buffers.

But what about the price to be paid for this increase in circuit complexity, in order to achieve that low noise level? The good news is that the 5532 device is a dual op amp, whereas the AD797 is only a single op amp. So we only need six 5532 devices at a current price of around £1. So the total op amp price tag for one channel is only about £6 – less than the price of a single AD797.

The end result is that by using Douglas Self's 'array' technique, we are able to achieve an impressive output noise level of –119.2dBV in our two channels. We do have to allow for a more complex PCB, but we believe that the end result is worth it.

Circuit description

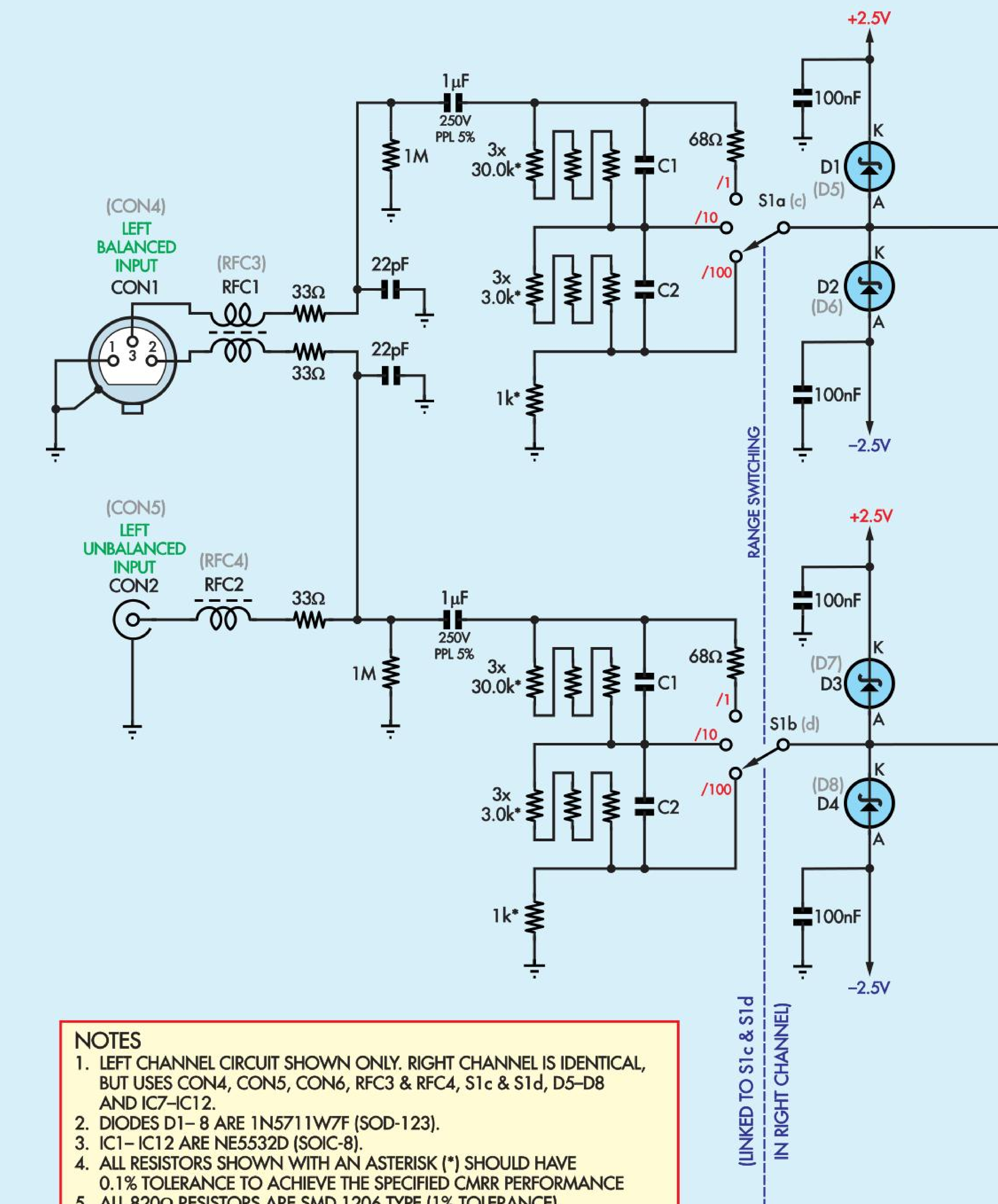
Now have a look at Fig.3, which shows the circuit of the left channel (the right channel is identical). Notice that we have added an unbalanced input, using CON2, to provide the option of connecting the attenuator channels to unbalanced signal sources.

As previously mentioned, inductors RFC1 and RFC2 have been included in series with the 33Ω suppressor resistors at the three inputs, to provide additional rejection of RFI/EMI signals. RFC1 is bifilar wound for improved rejection.

Note that we provided for discrete high-frequency compensation capacitors across the upper arms of the attenuator dividers, marked C1 and C2. We thought that these would be needed to compensate for the capacitance of the input voltage limiting diodes D1-D4 and the input capacitance of the array of voltage followers (IC1, IC3, IC4 and IC6).

However, during prototype testing, we discovered that discrete compensation capacitors were not necessary – partly due to the very low capacitance of D1-D4 and partly the incidental capacitance between the short lengths of wire connecting the lugs of range switch S1 to the PCB. As can be seen in the specification panel, the resulting frequency response is quite acceptable.

Note that the outputs of the four differential amplifiers (IC2a/b and IC5a/b) are combined using 10Ω (1%) resistors. This ensures that the final output at CON3 is an average of the four differential amplifier outputs and they won't 'fight' each other. As a result, there is no drop in signal gain but there is a welcome drop in noise output due to cancellation.



NOTES
1. LEFT CHANNEL CIRCUIT SHOWN ONLY. RIGHT CHANNEL IS IDENTICAL, BUT USES CON4, CON5, CON6, RFC3 & RFC4, S1c & S1d, D5–D8 AND IC7–IC12.
2. DIODES D1– 8 ARE 1N5711W7F (SOD-123).
3. IC1– IC12 ARE NE5532D (SOIC-8).
4. ALL RESISTORS SHOWN WITH AN ASTERISK (*) SHOULD HAVE 0.1% TOLERANCE TO ACHIEVE THE SPECIFIED CMRR PERFORMANCE
5. ALL 820Ω RESISTORS ARE SMD 1206 TYPE (1% TOLERANCE).
6. RFC1 – RFC4 ARE ALL WOUND ON FERRITE BEADS (5mm LONG, 4mm OD) USING 0.25mm ECW. RFC1 & RFC3 HAVE TWO BIFILAR TURNS, WHILE RFC2 & RFC4 HAVE TWO TURNS ONLY.
7. COMPENSATION CAPACITORS LABELLED C1 & C2 (TWO EACH PER CHANNEL) ARE NOT NORMALLY REQUIRED.

2-CHANNEL BALANCED INPUT ATTENUATOR
(SIGNAL PROCESSING, ONE CHANNEL)

Before leaving the circuit of Fig.3 we should perhaps draw attention to the notes panel. Part numbers for the right channel circuit are listed here and also shown on the circuit in grey.

Power supply details

Now let's move on to consider the Attenuator's power supply. Naturally, both the ±15V supplies for the op amps and the ±2.5V rails for the input clipping diodes need to be as quiet as possible if the full low noise performance of the attenuator itself is to be realised.

The first approach we tried was a fairly standard configuration with an external 17VAC plugpack feeding two half-wave rectifiers, each of which was then driving a 15V regulator fol-

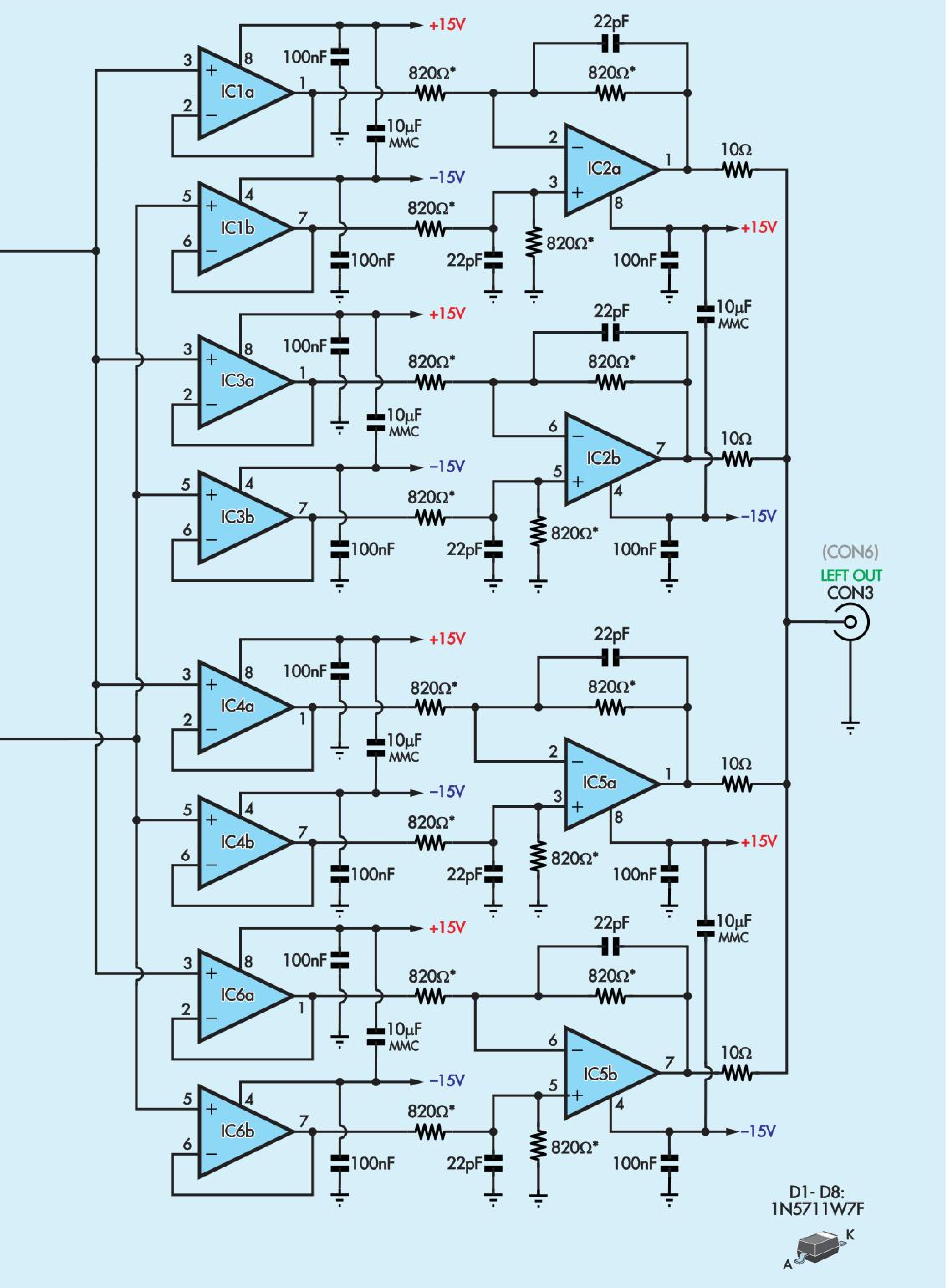


Fig.3: the complete circuit for the left channel of the *2-Channel Balanced Input Attenuator* (the right channel is identical). It's based on six NE5532D dual low-noise op amps (IC1a-IC6b, plus six more for the right channel.

lowed by a 2.5V regulator. Apart from the external AC plugpack, everything was on the same PCB as the rest of the attenuator's circuitry and therefore inside the shielding metal box.

While this did work, it proved to be virtually impossible to prevent 50Hz hum components and their harmonics from finding their way into the signal circuitry – possibly via radiation from the tracks on the PCB carrying current between the rectifier diodes and the input filter capacitors.

The only practical way to solve this problem was to remove the rectifiers, input capacitors and ±15V regulators from both the PCB and the box, and modify the design so that the unit is operated from a well-filtered and regulated external ±15V DC supply.

As it happens, we were also developing a *Universal Regulator* module, so the logical approach was to arrange for one configuration of this new *Universal Regulator* to be used for the *Attenuator's* external ±15V supply. You'll find the *Universal Regulator* described elsewhere in this issue.

Redesigning the attenuator in this way allowed us to simplify its internal power supply circuit to that shown in Fig.4. It has the two incoming 15V supply lines passing directly through to the attenuator's op amps and a pair of low-power TO-92 adjustable regulators (REG3 and REG4) used to provide the ±2.5V rails for the clipping diodes. A 3mm green LED (LED1) is connected between the two 2.5V rails via a 330Ω series resistor to provide power indication.

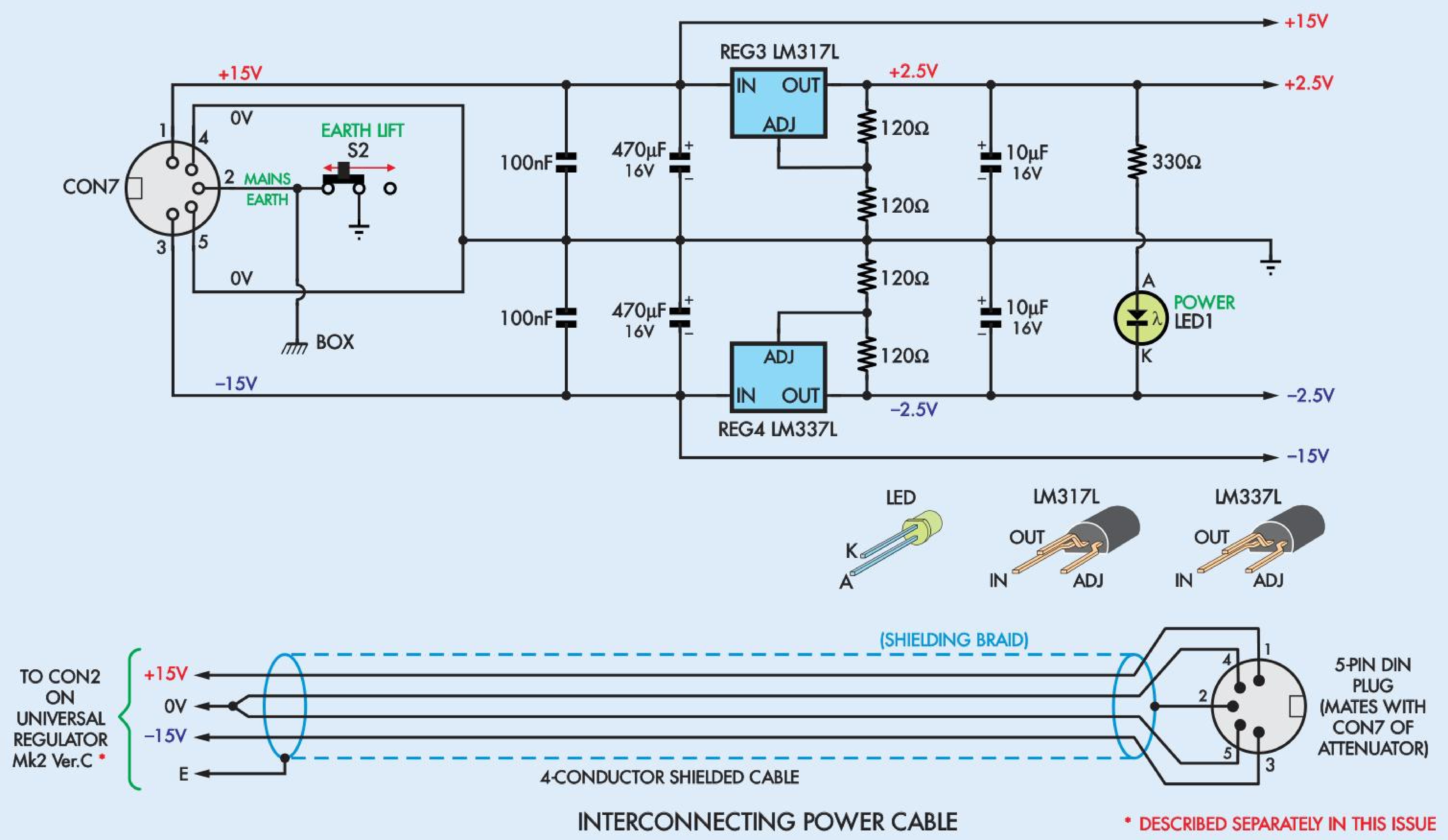
Because the 17V AC plugpack we're using with the *Universal Regulator* has an untapped secondary winding, we are forced to use a half-wave rectifier configuration. However, at the same time, this plugpack does provide a mains earth output lead and to make use of this we decided to pass this mains earth through the *Universal Regulator* PCB and thus make it available for load equipment like our *Balanced Input Attenuator*.

By connecting the *Attenuator* to the *Regulator* module using a four-conductor shielded cable, as shown at the bottom of Fig.4, we were able to bring the mains earth right through to pin 2 of the attenuator's power input connector (CON7). As a result, the attenuator's metal shielding box can be permanently connected to mains earth for shielding.

However, the earth/0V side of the attenuator's circuitry should not be connected permanently to this mains earth, because in some measurement situations this would have the potential to create an 'earth loop' and hence inject 50Hz hum into the attenuator's signal circuitry.

That's why we have fitted EARTH LIFT switch S2, so that the connection between the attenuator's earth and mains earth can be broken, to see which setting gives the better results.

Note that the cable used to connect the attenuator to the regulator module should be shielded, as shown at the bottom of Fig.4. This is to ensure that hum and EMI are not picked up and fed into the attenuator via the ±15V power lines. It is the shield braid that


+15V
+15V
+2.5V
+2.5V
REG3 LM317L
IN
OUT
ADJ
CON7
1
2
3
4
5
0V
0V
MAINS EARTH
EARTH LIFT
S2
BOX
–15V
100nF
100nF
470µF 16V
470µF 16V
120Ω
120Ω
120Ω
120Ω
10µF 16V
10µF 16V
330Ω
A
K
POWER LED1
REG4 LM337L
–2.5V
–2.5V
–15V
LED
K
A
LM317L
LM337L
OUT
IN
ADJ
(SHIELDING BRAID)
TO CON2 ON UNIVERSAL REGULATOR Mk2 Ver.C *
+15V
0V
–15V
E
4-CONDUCTOR SHIELDED CABLE
5-PIN DIN PLUG (MATES WITH CON7 OF ATTENUATOR)
INTERCONNECTING POWER CABLE
* DESCRIBED SEPARATELY IN THIS ISSUE

2-CHANNEL BALANCED INPUT ATTENUATOR INTERNAL POWER SUPPLY CIRCUITRY

Fig.4: the power supply circuitry built into the *Balanced Input Attenuator*, plus the wiring of the power cable used to run the unit from the *Universal Regulator* module described elsewhere in this issue.

also connects the mains earth to the attenuator, via pin 2 of CON7.

Construction

Building the *Attenuator* is straightforward, with all parts (except for range selector switch S1) mounted on a double-sided PCB, which is available from the *EPE PCB Service*, coded 04105151, measuring 160 × 80mm. This board is housed in a small extruded aluminium case measuring 170 × 85 × 54mm (W × D × H). It's similar in size to the case used for the QA400 Audio Analyser, making it easy to stack the two together.

Figs.5 and 6 shows the parts layout on the PCB. As shown, most of the parts are fitted to the top of the PCB. The only parts mounted on the bottom are output buffers IC5 and IC12 and their associated components. These are all fitted in the two areas indicated on the underside overlay (Fig.6).

All of the parts used in the input sections of the *Balanced Input Attenuator* (ie, ahead of range switch sections S1a-S1d) are conventional 'leaded' components. This was done to give maximum ruggedness and reliability, and to make the assembly easier. The power supply circuitry along the rear of the PCB also uses leaded components. However, SMD parts are used in the signal circuitry between S1 and output connectors CON3 and CON6.

PCB assembly

Here is our suggested order of assembly, to make this task as easy as possible:

Step 1: fit the SMD resistors and capacitors to the top of the PCB.

Step 2: fit SMD diodes D1-D8. These go on the top side near the front centre of the PCB (behind where S1 will be after final assembly). Be sure to fit each diode with the orientation shown in Fig.5.

Step 3: install the NE5532D dual op amp ICs to the top side of the PCB (IC1-IC4 and IC6-IC11). These come in an SOIC 8-lead SMD package. Make sure that you fit each IC with the correct orientation.

Don't worry if you get solder bridges between the pins when soldering these ICs in; they can be easily removed afterwards using solder wick and a hot iron.

Step 4: repeat step 1-3 for the parts on the underside of the PCB – see Fig.6.

Step 5: once all the SMD components are in place, install the resistors followed by the non-polarised capacitors and the polarised capacitors. Regulators REG3 and REG4 and LED1 can then go in. The latter must be fitted with its longer anode lead towards the centre rear of the board and with its body 18mm above the PCB (use a cardboard spacer between the leads).

The LED is later bent down through 90° so that it protrudes through a matching hole in the rear panel when the unit is assembled into the case.

Step 6: wind the four EMI suppression inductors (chokes). Each inductor is wound on a 5mm-long, 4mm-OD ferrite bead, using 0.25mm enamelled copper wire. All four inductors have

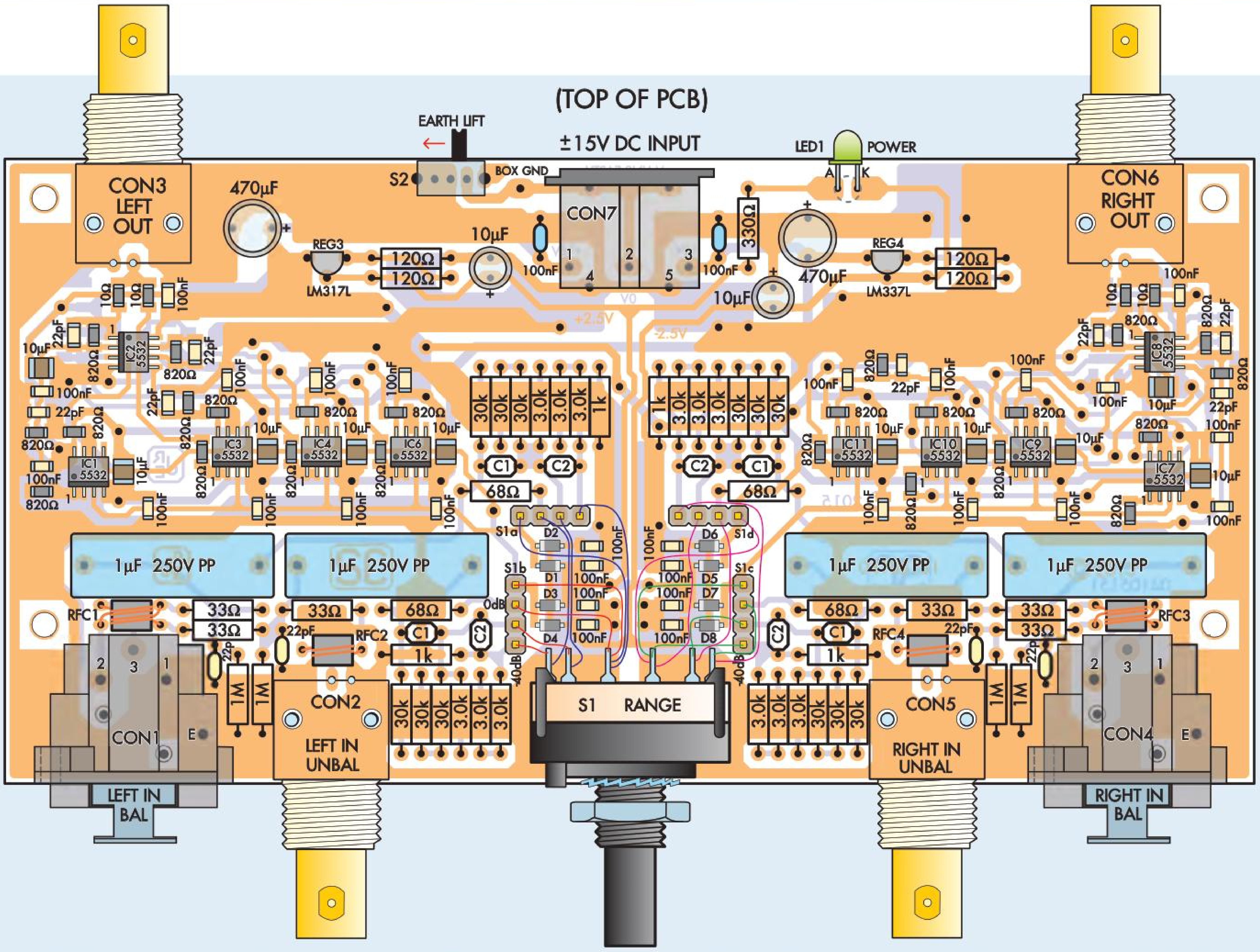
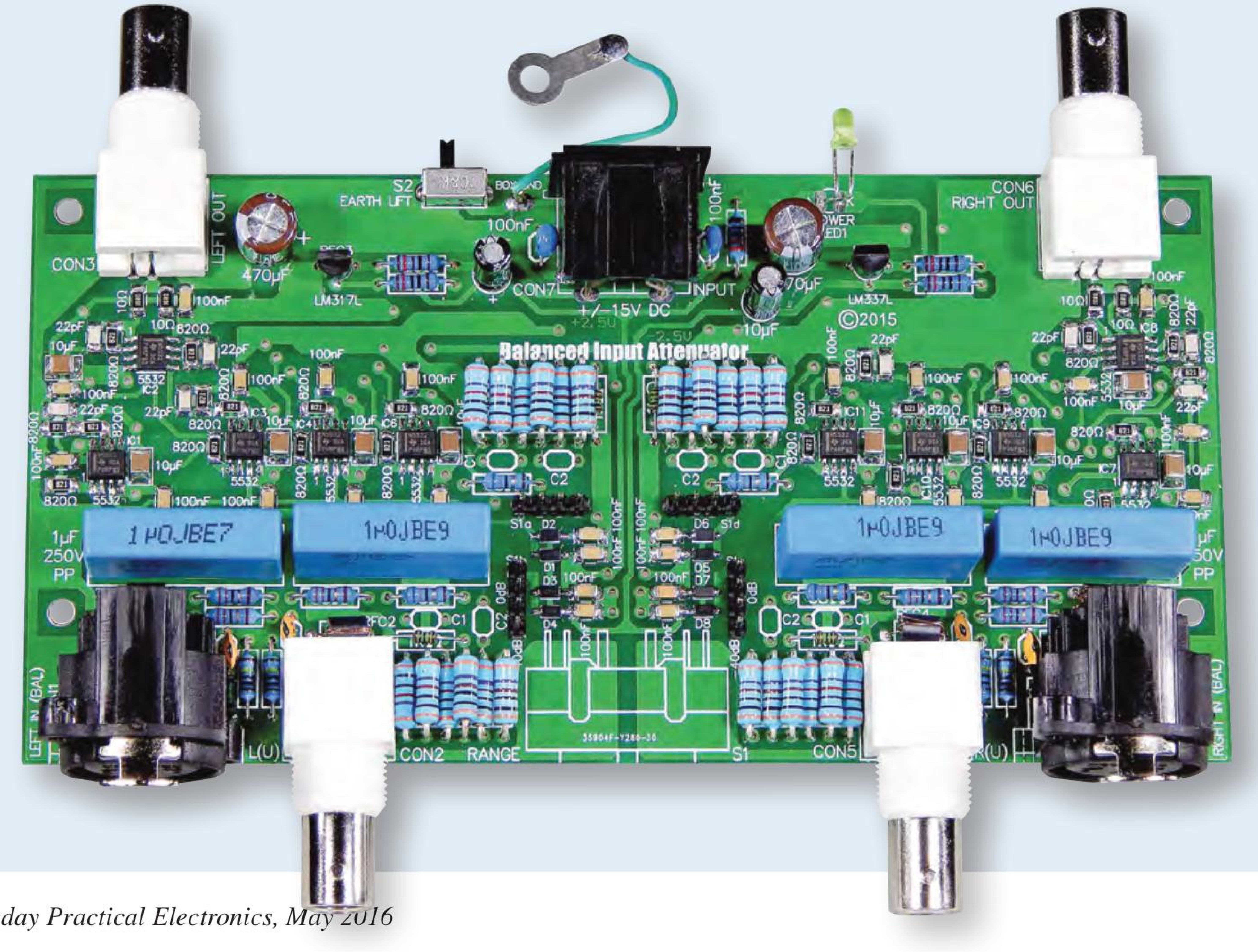
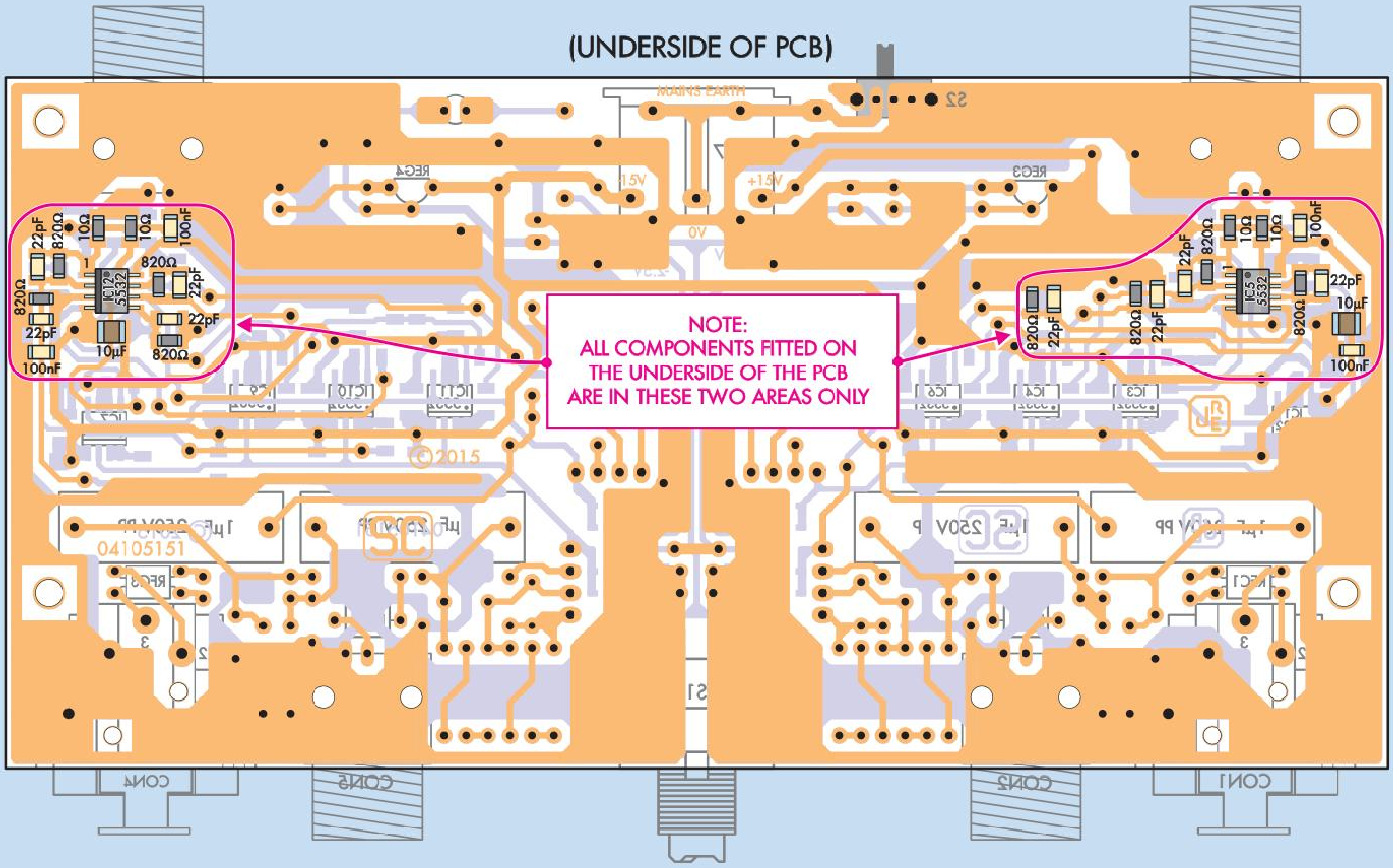

(TOP OF PCB)
EARTH LIFT
S2
BOX GND
±15V DC INPUT
CON7
LED1
POWER
A
K
CON3
LEFT
OUT
CON6
RIGHT
OUT
470µF
10µF
100nF
330Ω
REG3
LM317L
REG4
LM337L
120Ω
10Ω
820Ω
22pF
IC1
IC2
IC3
IC4
IC6
IC7
IC8
IC9
IC10
IC11
5532
30k
3.0k
1k
C1
C2
68Ω
S1a
S1b
S1c
S1d
D1
D2
D3
D4
D5
D6
D7
D8
0dB
40dB
1µF 250V PP
RFC1
RFC2
RFC3
RFC4
33Ω
1k
1M
CON1
E
LEFT IN
BAL
CON2
LEFT IN
UNBAL
S1 RANGE
CON5
RIGHT IN
UNBAL
CON4
RIGHT IN
BAL

Fig.5: follow this layout diagram to install the parts on the top of the PCB. A mixture of leaded (through-hole) and SMD components is used, with some SMD parts also fitted to the underside of the board, as shown on Fig.6. The only component not mounted on the PCB is range selector switch S1, which mounts on the front panel. The photo below shows the completed PCB.


Balanced Input Attenuator
©2015
S2
EARTH LIFT
CON3
CON6
RIGHT OUT
CON7
+/-15V DC
LM317L
LM337L
470µF
1µ0JBE9
CON2
RANGE
S1
CON5



NOTE: ALL COMPONENTS FITTED ON THE UNDERSIDE OF THE PCB ARE IN THESE TWO AREAS ONLY

Fig.6: here's how to install the SMD parts on the underside of the PCB. As shown, these parts are fitted to two areas at the top left and top right of the diagram.

only two full turns, but the winding details vary.

RFC2 and RFC4 have only a single 2-turn winding. By contrast, RFC1 and RFC3 have two turns wound in bifilar fashion, ie, two short lengths of wire are threaded through the bead together. The ends of these wires are then cut short (about 7mm long at each end) and tinned, ready to be soldered to the pads of the PCB.

Take care not to transpose the end connections of the two wires passing through RFC1 and RFC3, or you'll get a mysterious phase reversal!

The four inductors can now be fitted to the PCB (just behind the positions for CON1, CON2, CON4 and CON5).

Step 7: fit connectors CON1-CON7 to the top of the PCB. Be sure to push each one all the way down so that it sits flush against the PCB before soldering its leads.

Step 8: fit earth lift switch S2 to the rear of the PCB. This is a very small slider switch but it's no harder to solder in place than the SMD components.

Step 9: fit a single PCB terminal pin at the rear of the board, in the position labelled BOX GND in Fig.5 (just between S2 and CON7).

Step 10: complete the PCB assembly by fitting four 4-pin SIL headers in the positions indicated in the front centre of the PCB, grouped around diodes D1-D8 and their bypass capacitors. These headers will be used to make the connections to the four sections of range selector switch S1.

Preparing switch S1

The PCB assembly can now be put aside while you prepare switch S1, as follows:

Step 1: cut its control spindle to about 12mm long, then smooth off any burrs using a small file.

Step 2: cut a piece of 4-wire rainbow ribbon cable into four 35mm lengths and strip 5mm of insulation from both ends of all four wires. Carefully tin the ends of all wires, using a minimum of heat and solder.

Step 3: solder one end of each wire in each 4-wire cable to one section of switch S1. The first wire is soldered to the inner rotor lug, while the other three wires are soldered to the outer contact lugs, as shown in the accompanying photo. Note that in each group the second wire connects to the 'most clockwise' contact lug (looking from the front), the third wire to the centre contact lug and the fourth wire to the 'most anticlockwise' contact lug.

Step 4: solder the other ends of the ribbon cable wires to the connection lugs of four 4-way SIL sockets (again as shown in the photo). Note that in each case, the wire from the switch rotor connects to one end lug of the SIL socket, with the other three wires soldered to the remaining lugs of the socket in the same order as before. This should be clear if you look closely at the photo.

Alternatively, if you can obtain 4-way cables with 'DuPont' connectors already fitted, you can save yourself some effort. Just cut them to length and solder them to the rotary switch.

Your range selector switch assembly is now complete.

PCB front and rear panels

No case preparation is necessary since pre-drilled PCBs with screened lettering are used for the front and rear panels. These take the place of the

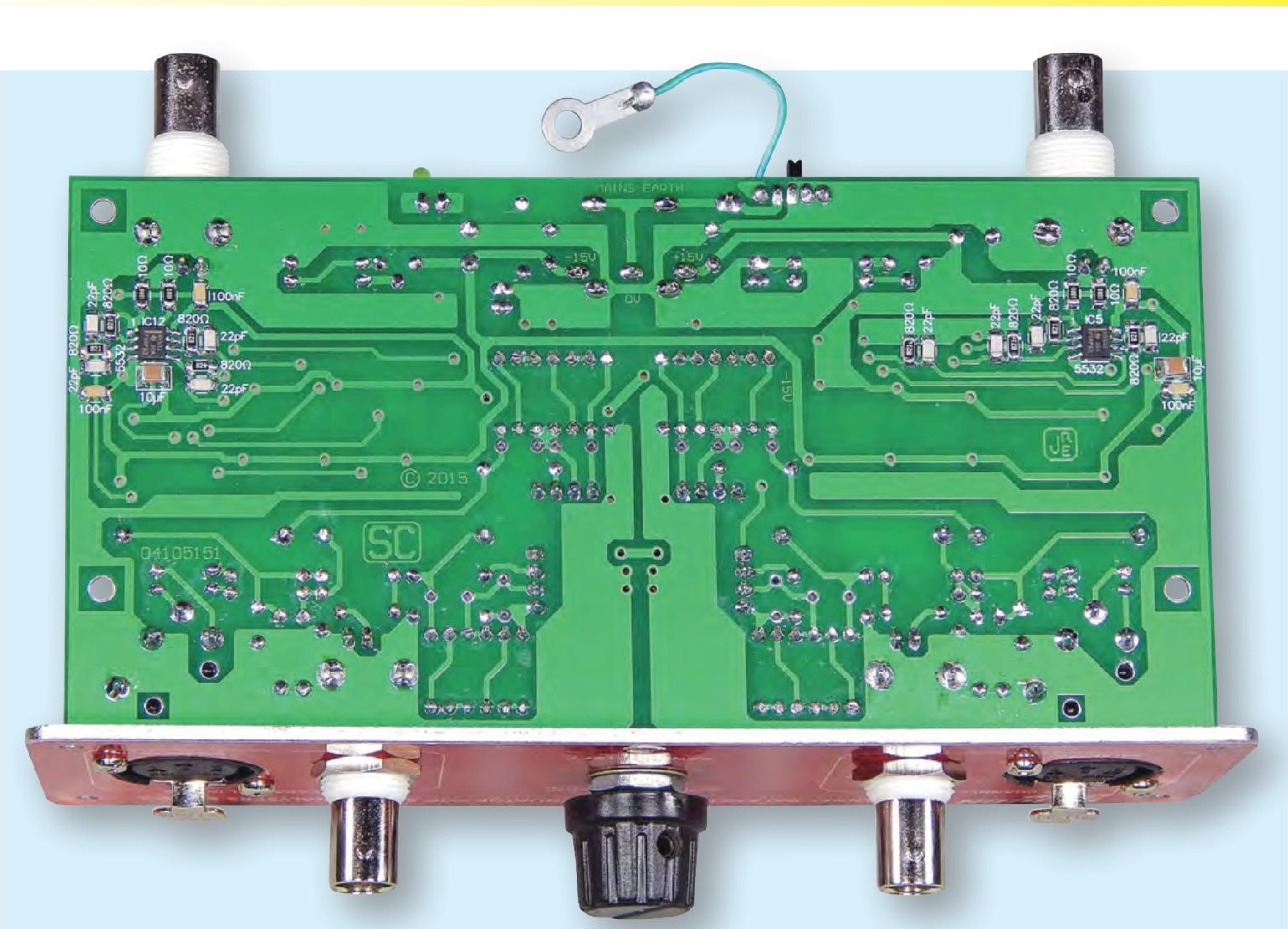


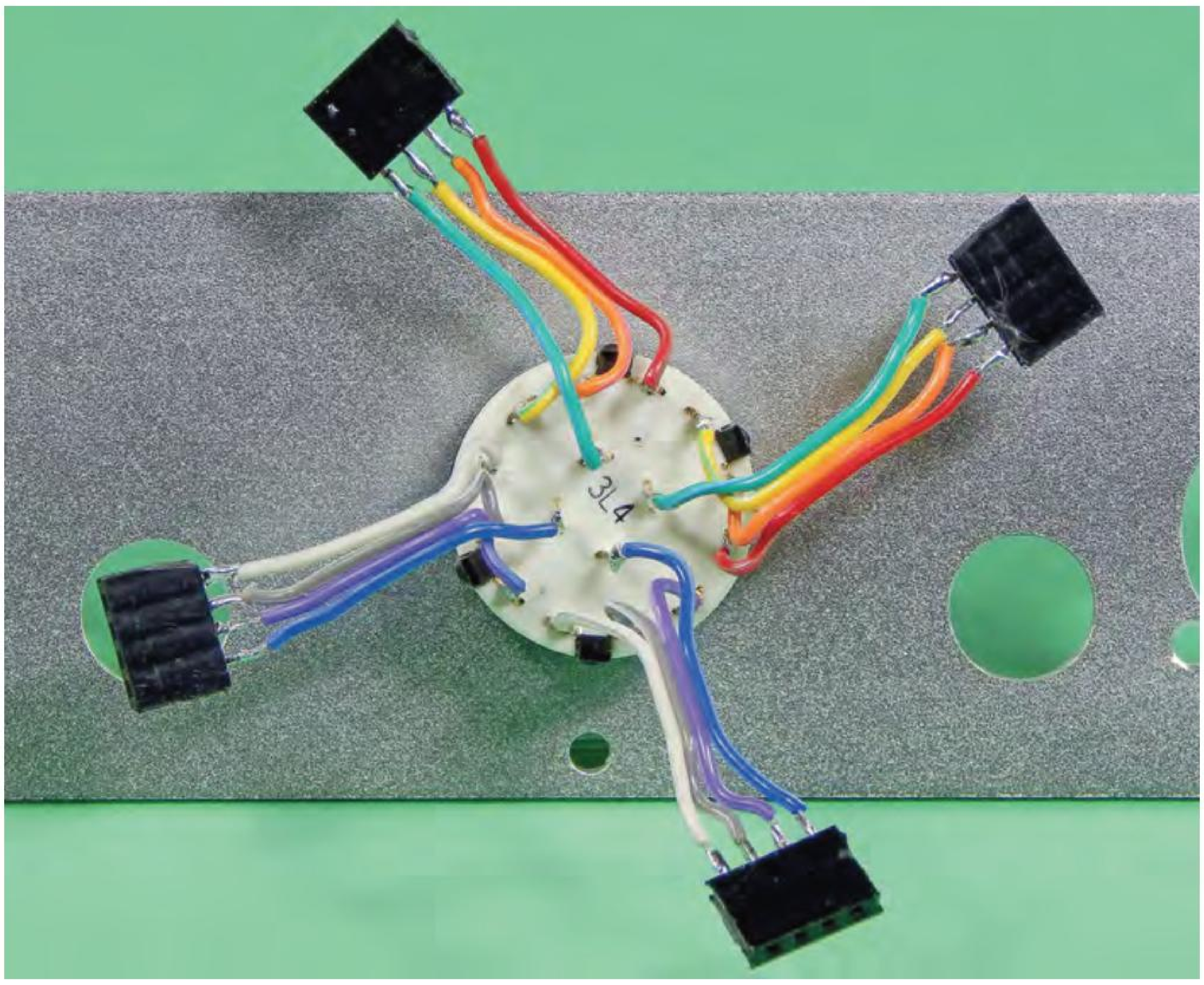
Fig.6: the underside of the PCB carries op amps IC5 and IC12 and their associated SMD parts. Be sure to orient the op amps correctly and use solder wick to clean up any solder bridges between their pins.

panels supplied with the case. The front-panel PCB is coded 04105152, while the rear panel PCB is coded 0410515. Both boards measure 170 × 64mm and can be purchased from the *EPE PCB Service*.

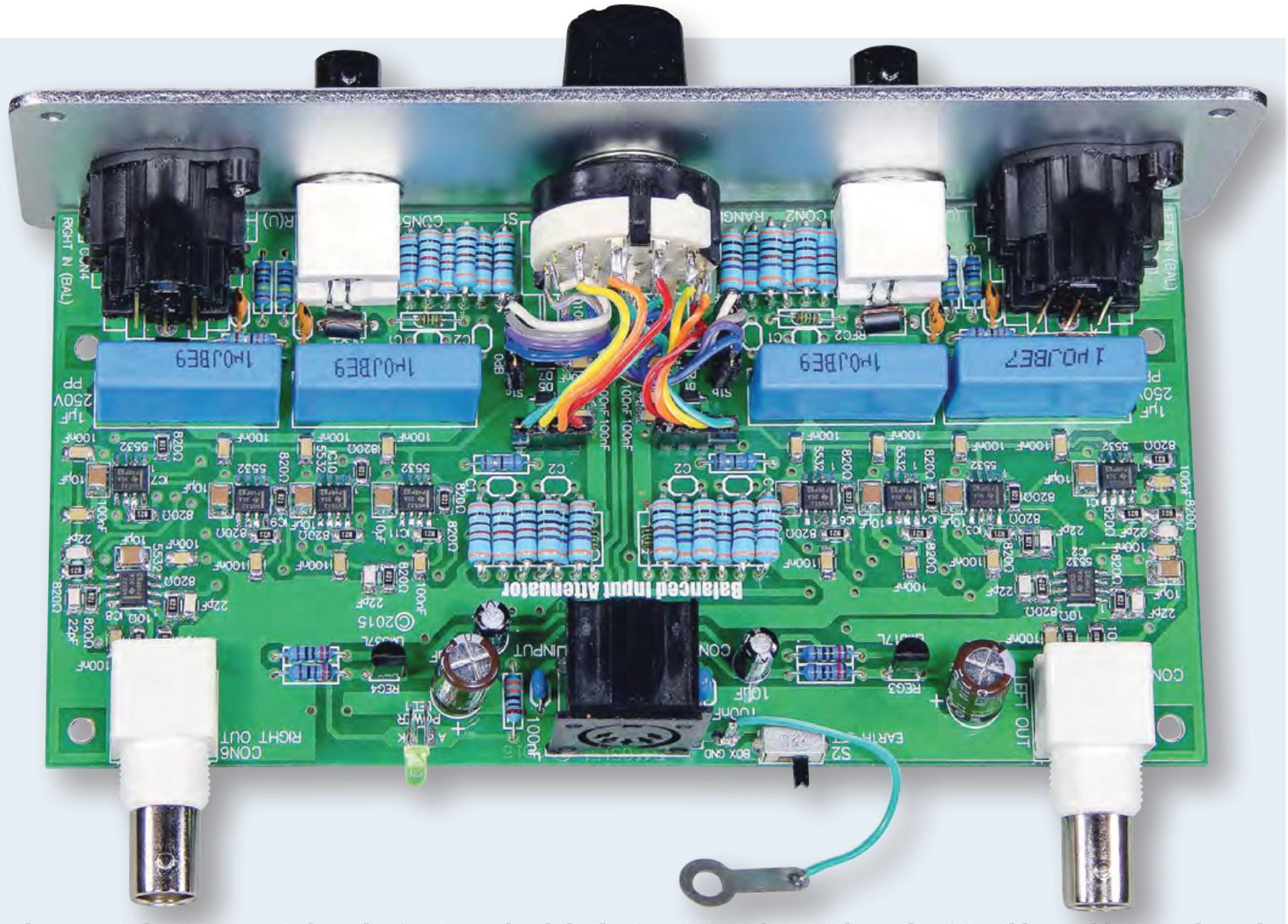
Once you have the panels, the next step is to fit the front panel PCB to the main PCB. That's done by first bringing it down at an angle so that the notches at the top of the XLR socket holes slip down behind the PUSH levers on the two sockets. At the same time, the two 13mm-diameter holes must be slipped over the BNC sockets, after which the panel is straightened and pushed all the way up to the PCB, so that it fits close to the four input sockets.

It's then just a matter of securing the panel in place by fitting the nuts that come with the BNC sockets and by installing pairs of 6G × 6mm self-tapping screws through the 3mm holes adjacent to each XLR socket.

Range selector switch S1 can now be attached to the front panel PCB. That's done by first removing its mounting



This close-up of the rear of range switch S1 shows how the four short ribbon cables are attached to its connection lugs and also to the four small SIL female header sections used to connect to the PCB.



Above: switch S1 is mounted on the front panel, while the four SIL sockets at the ends of its ribbon cables are plugged into matching pin headers on the PCB (see text for details on socket orientation). Note: this photo shows the original metal front panel supplied with the case, whereas the final version uses a PCB front panel and a PCB rear panel. Both the front and rear panel PCBs are available from the *EPE PCB Service*.

nut and checking to make sure that its locating spigot is set correctly to give three positions. The switch is then fed through its mounting hole and secured by doing up its mounting nut to hold it firmly in position.

S1's knob can then be fitted to its spindle – its grub screw tightened firmly.

Once the switch is in place, connect the four SIL sockets to their matching pin headers on the PCB. **The 'rotor wire' end of each socket goes to the header end labelled S1a, S1b, S1c or S1d.**

As shown on Fig.5, these labels are at the rearmost ends of the headers for S1b and S1c, while they are at the far left and far right of the headers for S1a and S1d. It's important to get these socket/header connections correct, otherwise you'll get some very strange results.

Final assembly

Now for the final assembly – fitting the front-panel/PCB assembly into the case. There are no mounting screws or pillars, because the extruded case has a series of horizontal PCB mounting slots running along each inside end. The main PCB simply slips snugly into the lowest slot at each end, until the front panel PCB meets the case. The back of the main PCB will then be only about 1mm in from the rear of the case, so that the power socket is accessible when the rear panel PCB is later fitted in place.

Once the PCB assembly has been slid into place, secure it using five of the supplied M3 × 12mm socket-head screws (these go through the holes in the front panel). However, before fitting the screw into the lower front-centre hole, it's a good idea to fit a thin M3 star lockwasher *between* the panel and the case. **This is to make sure that there's a good electrical connection between the case and the front panel PCB earth pattern when the screw is tightened up.**

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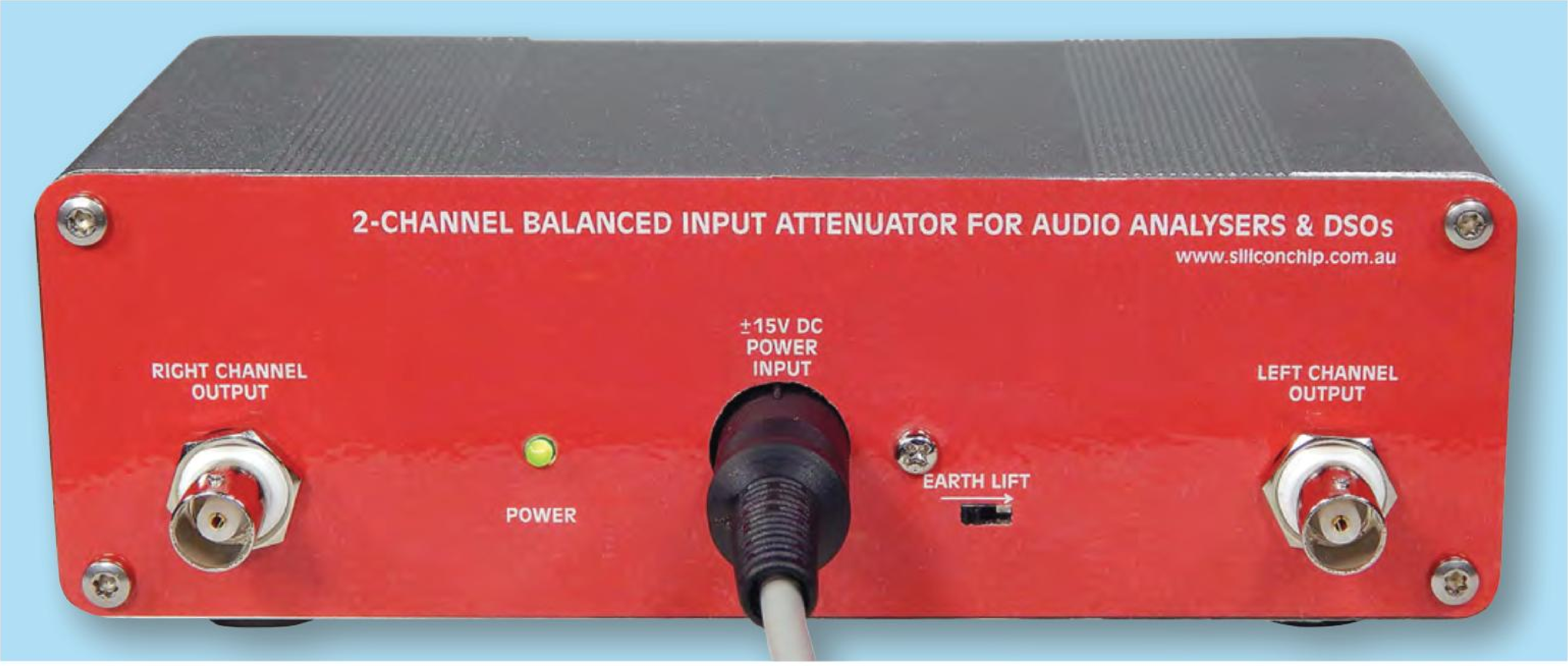

The left and right channel BNC output sockets, the earth lift switch and the green power LED protrude through matching holes in the rear panel. Access is also provided through the rear panel to the 5-pin DIN power supply socket.

The rear panel PCB is attached to the rear of the case using the five remaining M3 × 12mm screws, but before doing this, there are two small jobs to do. The first is to fasten a small solder lug to the inside of this PCB, using an M3 × 6mm machine screw, M3 nut and star lockwasher. This screw passes through the 3mm hole in the rear panel PCB just to the right of the 15mm diameter power input hole in the centre (and just above the rectangular hole for the earth lift switch actuator).

Fit the star lockwasher over the screw before fitting the solder lug

Parts List

1 double-sided plated-through PCB, available from the *EPE PCB Service*, coded 04105151, 160 × 80mm
1 front panel PCB, available from the *EPE PCB Service*, coded 04105152, 170 × 64mm
1 rear panel PCB, available from the *EPE PCB Service*, coded 04105153, 170 × 64mm
1 aluminium instrument case, 170 × 85 × 54mm (W × D × H)
1 ±15V DC power supply assembly plus 17VAC earthed plugpack (see text)
4 ferrite beads, 4mm OD × 5mm long
1 200mm length of 0.25mm enamelled copper wire (for winding RFC1-RFC4)
1 4-pole 3-position rotary switch (S1)
1 instrument knob, 20mm diameter with grub-screw
1 subminiature SPDT slide switch, PCB mounting with side actuator (S2)
2 3-pin XLR compact female sockets, 90° PCB-mount (CON1, CON4)
4 BNC sockets, 90° PCB-mount (CON2,CON3,CON5, CON6)
1 5-pin DIN socket, 90° PCB-mount (CON7)
1 5-pin DIN line plug
1 1m length 4-core shielded cable
4 4-pin SIL header strips
4 4-pin SIL female headers
4 35mm lengths of 4-wire ribbon cable or 2 × 4-way cables with DuPont header plugs at each end (these also replace the SIL female headers)
4 6G × 6mm self-tapping screws
1 M3 × 6mm machine screw
1 solder lug
1 M3 star lockwasher
2 thin M3 star lockwashers
1 M3 nut
1 PCB terminal pin, 1mm diameter
1 50mm length of insulated hook-up wire
4 adhesive rubber feet

Semiconductors
12 NE5532D dual low-noise op amps, SOIC-8 SMD package (IC1-IC12)
1 LM317L adjustable regulator, TO-92 (REG3)
1 LM337L adjustable regulator, TO-92 (REG4)
1 3mm green LED (LED1)
8 1N5711W-7-F Schottky diode, SOD-123 SMD package (D1-D8)

Capacitors
2 470μF 16V RB electrolytic
2 10μF 16V RB electrolytic
12 10μF 35V MLCC, SMD 1210, X7R dielectric
4 1μF 250V polypropylene 5%
32 100nF 50V MLCC, SMD 1206, X7R dielectric
2 100nF multilayer ceramic
4 22pF 100V disc ceramic, NP0
16 22pF 50V ceramic, SMD 1206, C0G/NP0 dielectric

Resistors (1% tolerance)
4 1MΩ 0.5W metal film
12 30kΩ 0.5W metal film (0.1%)
12 3.0kΩ 0.5W metal film (0.1%)
4 1kΩ 0.5W metal film (0.1%)
32 820Ω 1/8W, SMD 1206 (0.1%)
1 330Ω 0.5W metal film
4 120Ω 0.5W metal film
4 68Ω 0.5W metal film
6 33Ω 0.5W metal film
8 10Ω 1/8W, SMD 1206

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and the nut. This will ensure a good electrical connection between the solder lug and the rear panel PCB earth pattern when the assembly is tightened up.

That done, cut a short length (say 50mm) of insulated hook-up wire, strip about 5mm of insulation from each end and tin the wires. One end of this wire is then soldered to the solder lug on the inside of the rear panel, while the other end is soldered to the PCB terminal pin at the rear of the PCB (between CON7 and earth lift switch S2).

The second small job is to bend LED1's lead down by 90° (so that it faces outwards) at a point about 10mm up from the PCB. This will ensure that the LED's body will line up with its matching hole in the rear panel PCB and protrude slightly through it when the rear panel is fitted.

Once that's done, position the earth lead so that it won't get damaged, then fit the real panel. Make sure that LED1 and S2 pass through their matching holes in the panel, then fit the mounting nuts to CON3 and CON6 and the five remaining case assembly screws.

Another lockwasher

As with the front panel, it's a good idea to fit a thin M3 star lockwasher between the rear panel and the lower centre of the case, before you fit the lower centre screw. This is again to ensure that there will be a good electrical connection, this time between the rear panel and the case once that screw is tightened. It also means that, the case (and both the front and rear panels) will be reliably connected to mains earth for shielding when the *Balanced Input Attenuator* is connected to the *Universal Regulator*.

Your *Balanced Input Attenuator* is now assembled and ready for use. However, it's a good idea to fit four adhesive rubber feet to the underside of the case, so that it can be placed on top of the QA400 Analyser or another instrument without scratching it.

Now, just wire up the power cable, using the diagram at the bottom of Fig.4 as a guide. This will allow you to connect the unit to the *Universal Regulator*. Once you've done this, plug the 17VAC plugpack into a power outlet and check that LED1 on the rear of the attenuator lights, to show that it has powered up correctly.

Resistors and thermal noise

Back in 1926, John Johnson of Bell Labs in the USA discovered that electrical noise was generated in all electrical conductors at temperatures above absolute zero (0K = –273°C), due to thermal agitation of charge carriers (eg, the electrons). This happens regardless of whether the conductor concerned has any voltage applied to it or is conducting any current. It is basically determined by the resistance of the conductor and the temperature, although the bandwidth of measurement also plays a role in terms of the actual noise voltage.

Johnson's Bell Labs colleague Harry Nyquist worked out how this noise is generated and came up with a number of expressions which allow its power density and/or RMS voltage level over a given bandwidth to be calculated.

The most useful of these expressions is the one to calculate RMS noise voltage for a given measurement bandwidth:

$$V_n = \sqrt{(4.k_B.T.R.\Delta f)}$$

where k_B is Boltzmann's constant in joules per kelvin (1.38×10^{-23}), T is the temperature in kelvins (°C + 273), R is the resistance in ohms and Δf is the measurement bandwidth in Hertz.

For example, a 1kΩ resistor at 25°C (= 298K) will generate an RMS thermal noise voltage of 0.5876μV (ie, 587.6nV or –124.618dBV), when measured over a bandwidth of 20,980Hz (20Hz – 21.0kHz).

Note that thermal or Johnson (or Johnson/Nyquist) noise is quite different from Shot noise, which is the additional noise generated in a conductor when a voltage is applied and a current begins to flow through it.

Thermal noise also has nothing to do with the actual conducting material inside a resistor or other component – it's purely to do with the resistance and the temperature. So if you have two 1kΩ resistors, one with a metal film element and the other with a carbon composition element, they will both generate the same thermal noise at 298K when measured over the same bandwidth.

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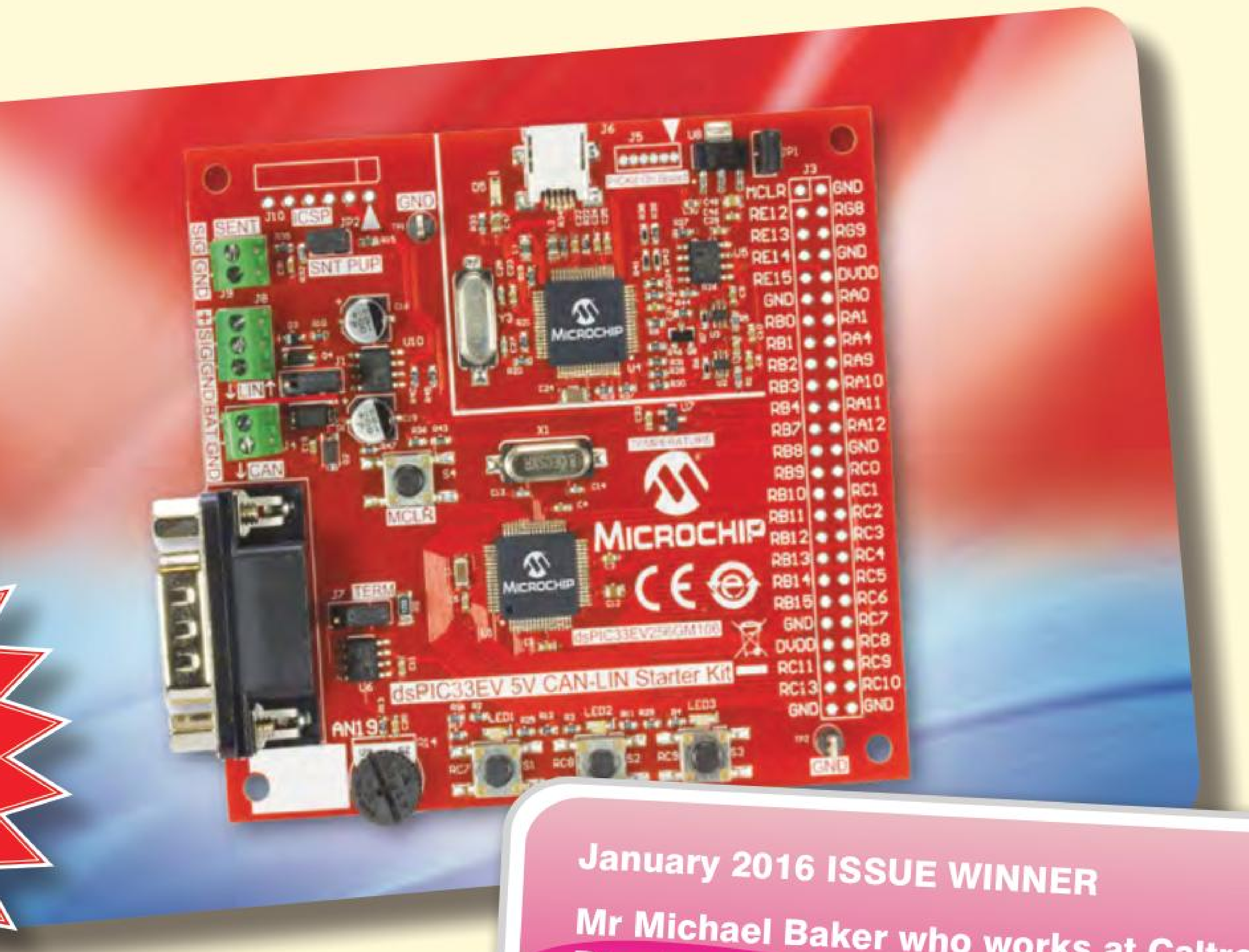

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Appliance Earth Leakage Tester

By JOHN CLARKE

LEGAL LEAKAGE LIMITS
CLASS 1 (MAINS EARTHED) 5mA MAX
PORTABLE RCDs WITH FUNCTIONAL EARTH 2.5mA MAX
CLASS 2 (DOUBLE INSULATED) USE EARTH PROBE TO EXPOSED METAL 1mA MAX
CORD EXTENSION SETS PORTABLE OUTLETS AND RCDs 1mA MAX
(ENSURE APPLIANCE IS POWERED AND SWITCHED ON FOR TEST)
APPLIANCE EARTH LEAKAGE TESTER
EARTH PROBE
DC OUT
AC OUT
TO DMM (mV DC RANGE) 100mV DC = 1mA LEAKAGE
SCOPE OUTPUT (AC)
COM
POWER
Supernet 8050T
Digital Terrestrial Receiver
DVB

Used in conjunction with a digital multimeter, this *Appliance Earth Leakage Tester* can be used to check the safety of earthed and double-insulated equipment. Most importantly, it tests equipment when it is powered from the 230VAC mains supply and operating normally.

Features and specifications

Features

- Monitors earth leakage current via imbalance between live and neutral current flow
- Measurement displayed on multimeter in voltage mode
- AC output and true RMS (DC) output
- Easy measurement conversion (100mV on the DMM = 1mA leakage current)
- Powered from a 9V battery; power LED indicates battery state

Specifications

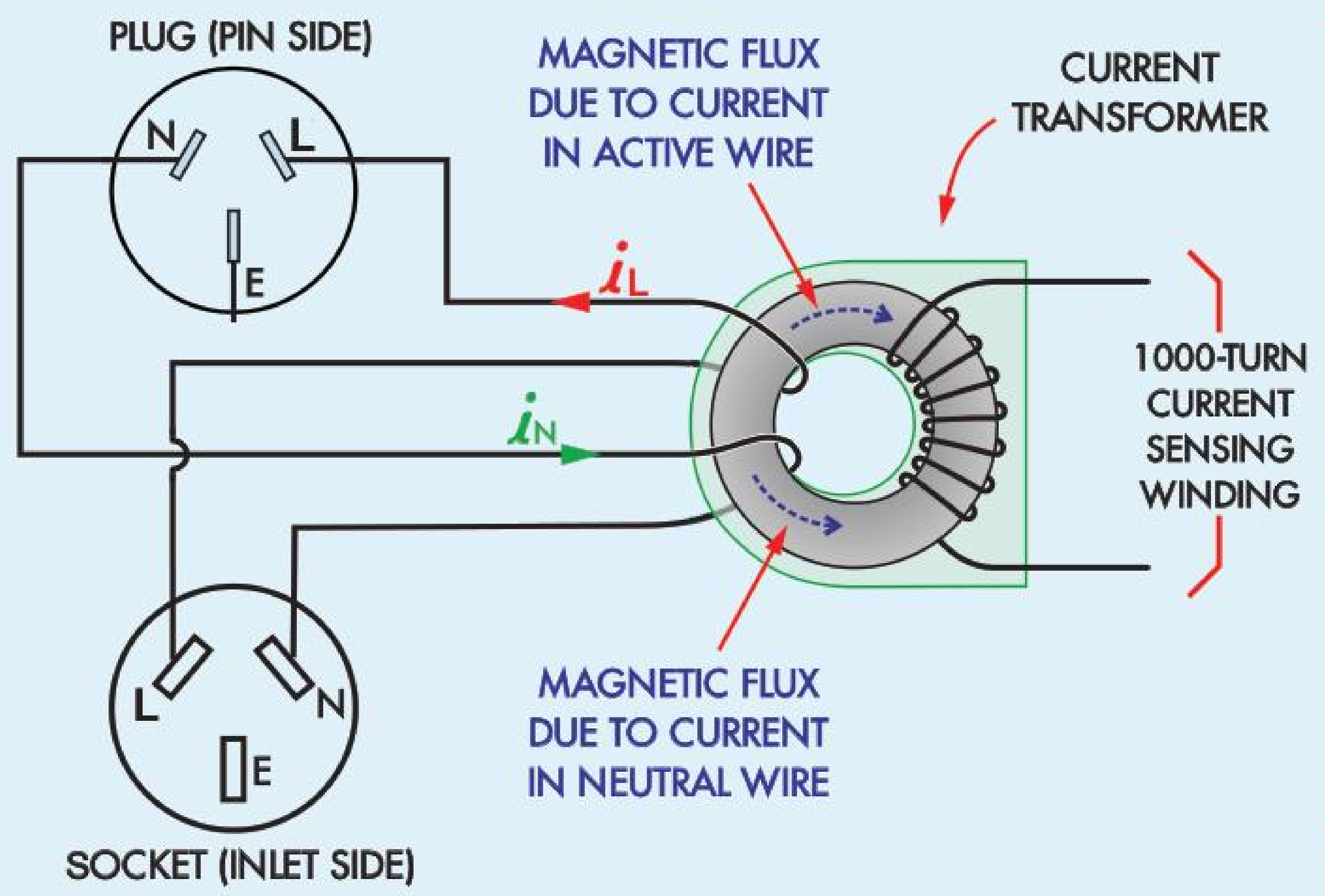
Frequency response: <10Hz to >6kHz (-3dB)
Linearity: <1% deviation for measurements from 1-5mA
True RMS: crest factor up to 5
Power supply: 9V battery
Current drain: typically 2.5mA
Battery voltage: operates down to 7.4V; indicator LED indicates battery state

IN LAST MONTH'S issue, we presented the *Appliance Insulation Tester* which tests at 500V or 250V DC. However, that tester cannot do a proper test of any appliance which is switched on by remote control or does not use a mechanical on/off switch.

Such appliances are very common these days, starting from large-screen TV sets and working down from there. Chances are that you have a dozen or more appliances with remote-controls or pushbutton switches. In the latter class will be washing machines, microwave ovens and vacuum cleaners.

So this *Appliance Earth Leakage Tester* is an essential item to have on hand if you want to be sure that none of your appliances presents a safety hazard. As we noted in last month's

Agilent
U1253B
10.995
24.8°C
mV
50mV
AUTO
True RMS OLED Multimeter


PLUG (PIN SIDE)
N
L
E
MAGNETIC FLUX DUE TO CURRENT IN ACTIVE WIRE
CURRENT TRANSFORMER
i_L
i_N
1000-TURN CURRENT SENSING WINDING
L
N
E
MAGNETIC FLUX DUE TO CURRENT IN NEUTRAL WIRE
SOCKET (INLET SIDE)

TALEMA INDIA 10/14
AC1015

A life-size view of the Talema AC1015 15A current transformer used in this design.

Fig.1: how earth leakage current is measured. The live and neutral leads to the appliance are fed through a current transformer and if the currents in them are unequal, the transformer produces an output from its secondary.

article on the *Appliance Insulation Tester*, you should not rely on your home's safety switches (RCDs) to fully protect you.

If one of your appliances does become faulty and you are unlucky enough to be in the fault current path, the RCD may well save your life but you could still get a very severe shock in the process. And you if you have a weak ticker, the RCD may not save your life – there is no absolute guarantee!

Measuring earth leakage

Our *Appliance Earth Leakage Tester* is based on a low-cost current transformer. It comprises a ferrite toroid through which are wound 1000 turns of enamelled wire connected to two output pins. The transformer is encapsulated in resin with a hole in the centre to allow the primary windings to be fed through. Isolation between the centre hole and secondary winding is 4kV. Further isolation is provided because the wires that pass through the core will also be insulated.

The particular transformer we are using is rated up to 15A primary current and up to 60A before core saturation.

To measure the earth leakage current of an appliance, the live and neutral wires are passed through the centre hole of the current transformer, as shown in Fig.1. If there is no earth leakage current, the magnetic flux due to the live and neutral currents will cancel and there will be no output voltage generated by the 1000-turn secondary winding of the transformer.

On the other hand, if the live and neutral currents are not exactly the same, then the difference between those currents will be due to a leakage path to earth. As a result, there will be a differential magnetic flux and there will be a resulting output voltage from the 1000-turn secondary winding.

For Class 1 appliances where the exposed metal parts are connected to mains earth, the leakage current can be directly measured.

Alternatively, for double insulated equipment where the mains earth is not connected to the appliance, an earth probe must used to connect any exposed metal to the mains earth so that the leakage current can be measured.

Amplifying the voltage

Now even though the transformer has a 1000-turn secondary winding, its output is quite tiny at about 1µA per mA (or 100µV/mA across a 100Ω load) and this is far too low to be useful. We would need to amplify this by a factor of 1000 to produce a useful signal of 100mV per mA of differential current.

This amplified signal can be measured directly with a digital multimeter, using the low AC voltage ranges. Mind you, if you do use a digital multimeter, it should be a 'true RMS reading' meter. Multimeters that do not have true RMS readings are prone to severe reading errors if the leakage current waveform is non-sinusoidal, as is common with switch-mode supplies and rectified supplies in mains equipment.

Since most DMMs are not 'true RMS reading', the circuit described here includes a true RMS AC-to-DC converter to allow the multimeter to accurately measure the leakage current on its DC voltage ranges.

As an aside, when an appliance contains a switch-mode power supply, any earth leakage current will contain components at 50Hz, 100Hz, plus many higher frequency components exceeding several kHz. Electromagnetic interference (EMI) suppression filtering in the appliance will suppress but not eliminate frequencies higher than this.

Circuit details

As mentioned above, the signal output from the current transformer's winding is very low with a 100Ω resistive load. A low-resistance load is necessary to ensure the output is linear with respect to the appliance earth leakage current.

However, an alternative method that does not require a low value loading resistor, but still results in a linear response is to convert the transformer secondary winding's current to a voltage using a transimpedance amplifier.

This is shown in the main circuit of Fig.2, which has one side of the current transformer secondary tied to half the supply voltage (Vcc/2) and fed to the non-inverting input (pin 3) of op amp IC1, a TLE2071CP. IC1's inverting input (pin 2) monitors the other side of the transformer via a 10µF capacitor and 150Ω resistor.

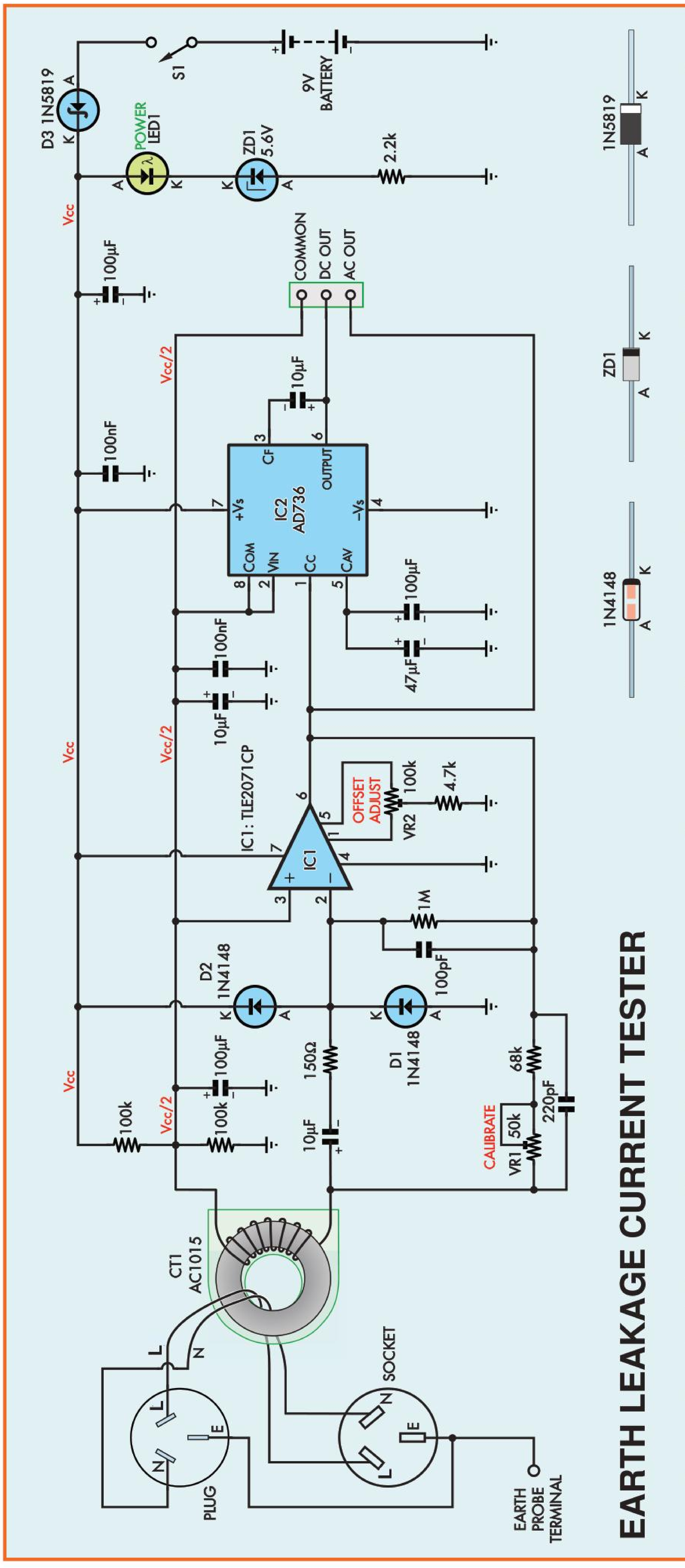

EARTH LEAKAGE CURRENT TESTER
D3 1N5819
K
A
S1
9V BATTERY
POWER LED1
ZD1 5.6V
2.2k
Vcc
100µF
Vcc/2
100nF
COMMON
DC OUT
AC OUT
10µF
IC2 AD736
+Vs
CF
OUTPUT
–Vs
COM
VIN
CC
CAV
100µF
47µF
100nF
10µF
IC1: TLE2071CP
IC1
OFFSET ADJUST
VR2 100k
4.7k
1M
100pF
D2 1N4148
D1 1N4148
150Ω
100k
100µF
10µF
68k
CALIBRATE
VR1 50k
220pF
CT1 AC1015
L
N
E
PLUG
SOCKET
EARTH PROBE TERMINAL
1N4148
ZD1
1N5819

Fig.2: the complete circuit diagram of the *Earth Leakage Current Tester*. The output from the current transformer is fed to IC1, which acts as a current-to-voltage converter. Its AC output at pin 6 is in turn fed to IC2, a true RMS AC-to-DC converter.

The *Appliance Earth Leakage Tester* is housed in a standard UB1 plastic utility box and is fitted with a PCB front panel. The panel comes pre-drilled with screened lettering, to minimise case preparation. (*UK readers will need to use UK-equivalent plug and socket connectors.*)

IC1 acts as the current-to-voltage converter. Its transimpedance value is 100mV/µA which, when combined with the transformer's input:output ratio, results in the required 100mV/mA of differential current. But due to the way it works, no voltage appears across the transformer, so the load impedance 'seen' by the transformer is very low.

The 150Ω resistor between the transformer and op amp input pin 2 is there to limit current flow in diodes D1 and D2 should the output from the transformer exceed the supply rails. Diode D2 limits the input to pin 2 at just over the Vcc supply, while D1 limits the input to just below the ground. Note that the earth leakage would need to be around 45A before the diodes begin to conduct, but that could happen with a major short to earth in an appliance under test.

The aforementioned transimpedance value is determined by the 68kΩ resistor and series-connected 50kΩ

LEGAL LEAKAGE LIMITS
CLASS 1 (MAINS EARTHED)
PORTABLE RCDs WITH FUNCTIONAL EARTH
5mA MAX
CLASS 2 (DOUBLE INSULATED) USE EARTH PROBE TO EXPOSED METAL
2.5mA MAX
CORD EXTENSION SETS
1mA MAX
PORTABLE OUTLETS AND RCDs
1mA MAX
(ENSURE APPLIANCE IS POWERED AND SWITCHED ON FOR TEST)
APPLIANCE EARTH LEAKAGE TESTER
DC OUT
TO DMM (mV DC RANGE) 100mV DC = 1mA LEAKAGE
AC OUT
SCOPE OUTPUT (AC)
COM

trimpot VR1 between pin 6 of IC1 and the transformer secondary. The 100pF and 220pF capacitors across the feedback resistances provide a ~6.5kHz high-frequency roll-off, preventing RF pick-up in the amplified waveform.

The DC offset at pin 6 due to Vcc/2 is zeroed out using VR2. Any DC offset will typically be within 0.34mV of the Vcc/2 rail, but in the worst case could be up to 4mV and this is fixed by adjusting this trimpot.

IC1's output connects to the AC output terminal (for measurement with a DMM) and is also fed to pin 1 of IC2, an AD736 true RMS AC-to-DC converter. As shown in Fig.3, the AD736 comprises an input amplifier, a full-wave rectifier, an RMS core, an output amplifier and a bias section. The input amplifier has two inputs: a high-impedance, buffered input at pin 2 and a low-impedance, wide dynamic range input at pin 1. We use pin 1 input as it produces a wider frequency response.

Parts List

1 double-sided PCB, available from the *EPE PCB Service*, coded 04203151, 86 × 130mm
1 PCB, available from the *EPE PCB Service*, coded 04203152, 88 × 26mm
1 blue PCB, available from the *EPE PCB Service*, coded 04203153, 90 × 151mm (front panel)
1 UB1 jiffy box, 158 × 95 × 53mm
1 15A current transformer, Talema AC1015 (CT1)
1 1.5m mains extension lead
1 150mm length of 10A earth wire (green/yellow)
1 double-screw BP connector to join Earth wires in mains cable
2 BP connectors to join live and neutral wires
1 9V PCB-mount battery holder
1 9V battery
2 8-pin DIL IC sockets (optional)
2 cordgrip grommets to suit 10A 3-core mains cable (7.4-8.2mm diameter) and 3mm-thick case (Do NOT use cable glands)
1 black shrouded safety multimeter test lead
1 set of shrouded banana to banana test leads
1 SPDT toggle switch, PCB-mount (S1)
1 red safety banana socket
1 black safety banana socket
1 green safety banana socket
1 yellow safety banana socket
3 No.4 × 6mm self-tapping screws for 9V battery holder
4 M3 tapped × 15mm spacers
8 M3 × 6mm machine screws
6 100mm cable ties
3 PC stakes
1 50mm length of 0.7mm diameter tinned copper wire
1 50kΩ multi-turn trimpot (code 503) (VR1)
1 100kΩ multi-turn trimpot (code 104) (VR2)

Semiconductors
1 TLE2071CP PDIP low-noise high-speed JFET op amp (RS Components Cat. 834-140, element14 Cat. 2387529) (IC1)
1 AD736JNZ PDIP True RMS AC-to-DC Converter (RS Components Cat. 522-9133, element14 Cat. 9605061) (IC2)
2 1N4148 diodes (D1,D2)
1 1N5819 1A Schottky diode (D3)
1 5.6V 1W zener diode (ZD1)
1 3mm high brightness red LED (LED1)

Capacitors
3 100µF 16V PC electrolytic
1 47µF 16V PC electrolytic
3 10µF 16V PC electrolytic
2 100nF MKT
1 220pF ceramic
1 100pF ceramic

Resistors (0.25W, 1%)
1 1MΩ
2 100kΩ
1 68kΩ
1 10kΩ*
1 4.7kΩ
1 2.2kΩ
1 1kΩ*
1 150Ω
* for calibration

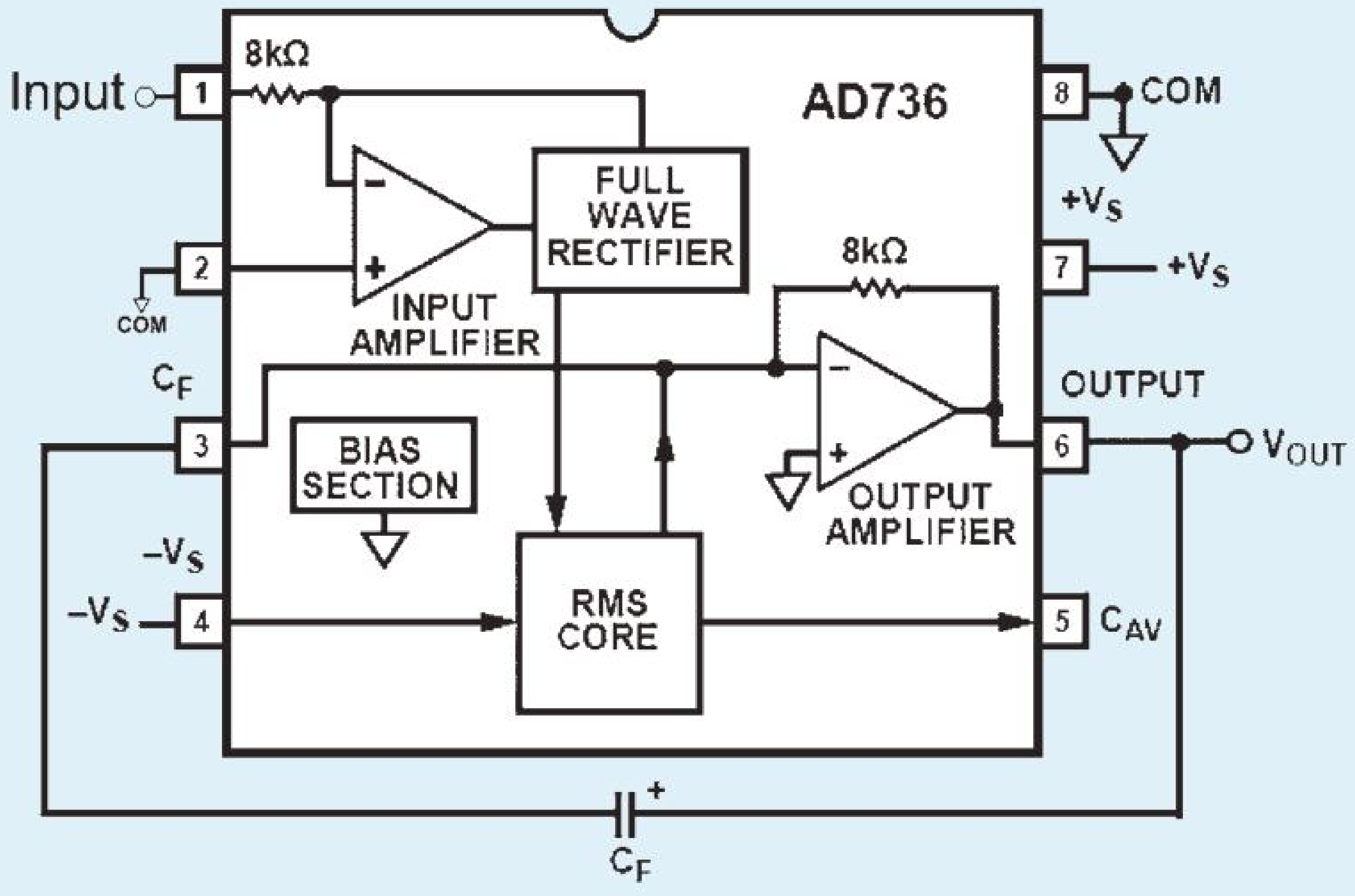
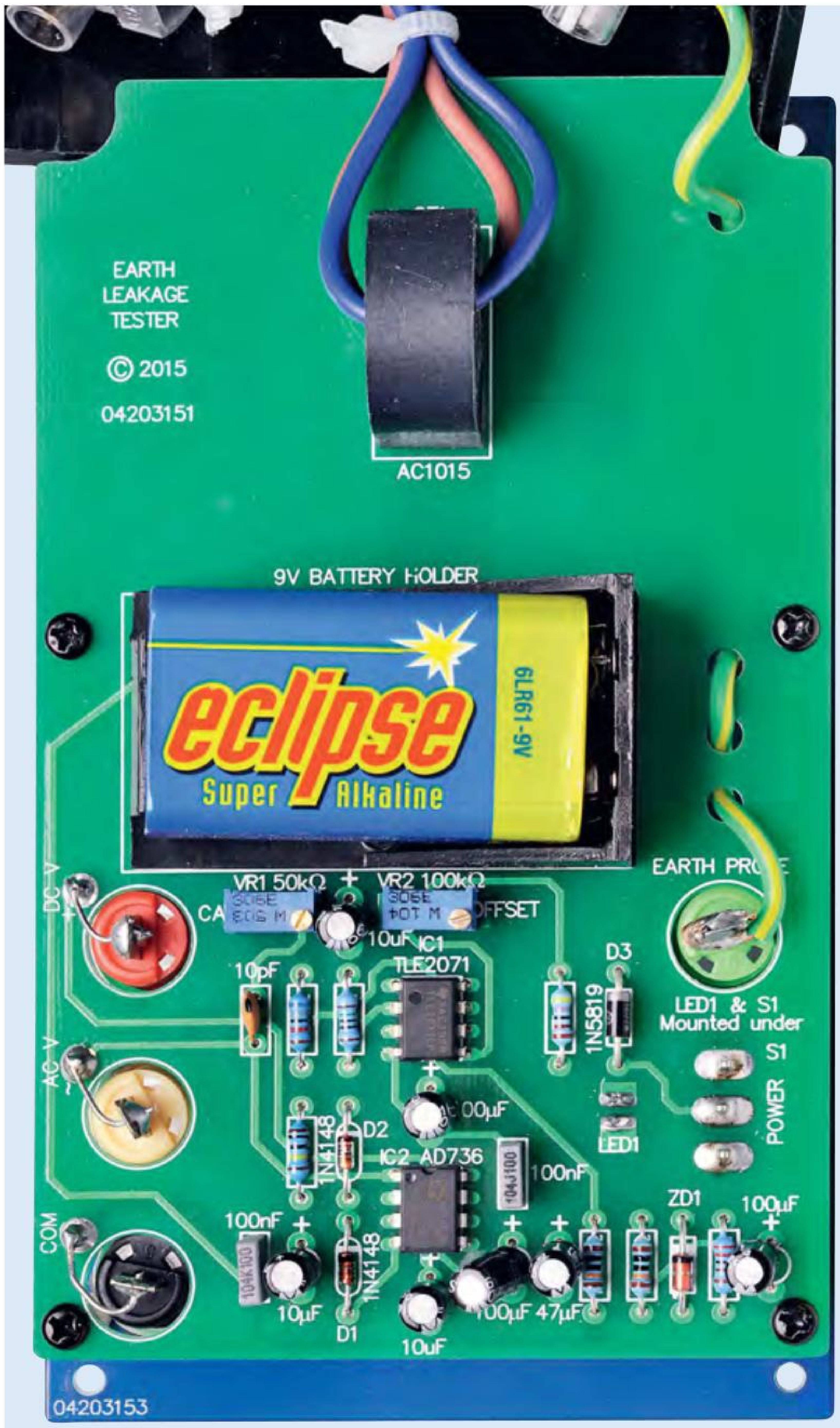

Input
8kΩ
AD736
1
2
COM
CF
3
–VS
–VS
4
FULL WAVE RECTIFIER
INPUT AMPLIFIER
BIAS SECTION
RMS CORE
8
COM
+VS
7
+VS
8kΩ
OUTPUT
6
VOUT
OUTPUT AMPLIFIER
5
CAV
CF

Fig.3: inside the AD736 True RMS AC-to-DC converter. It comprises an input amplifier, a full-wave rectifier, an RMS core, an output amplifier and a bias section.


EARTH
LEAKAGE
TESTER
© 2015
04203151
AC1015
9V BATTERY HOLDER
eclipse
Super Alkaline
6LR61-9V
EARTH PROBE
DC V
AC V
COM
VR1 50kΩ
VR2 100kΩ
CAL
OFFSET
10µF
IC1
TLE2071
10pF
D3
1N5819
LED1 & S1
Mounted under
S1
POWER
LED1
D2
1N4148
IC2 AD736
100nF
ZD1
100µF
47µF
10µF
D1
04203153

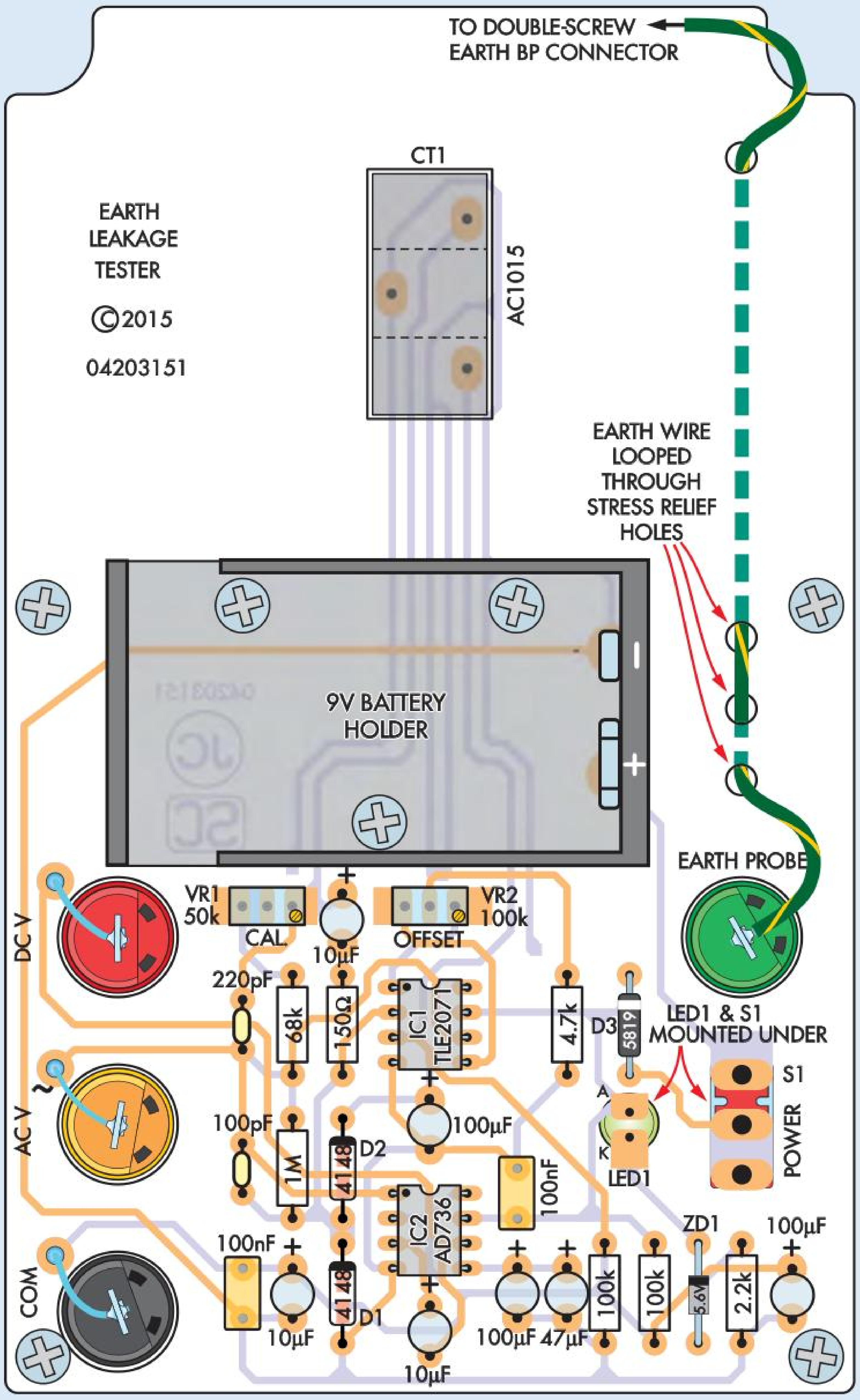

TO DOUBLE-SCREW
EARTH BP CONNECTOR
CT1
AC1015
EARTH
LEAKAGE
TESTER
©2015
04203151
EARTH WIRE
LOOPED
THROUGH
STRESS RELIEF
HOLES
9V BATTERY
HOLDER
−
+
EARTH PROBE
DC V
AC V
COM
VR1
50k
CAL
VR2
100k
OFFSET
10µF
220pF
68k
150Ω
IC1
TLE2071
4.7k
D3
5819
LED1 & S1
MOUNTED UNDER
S1
POWER
A
K
LED1
100pF
1M
4148
D2
100µF
100nF
IC2
AD736
100nF
4148
D1
10µF
10µF
100µF
47µF
100k
100k
ZD1
5.6V
2.2k
100µF

Fig.4: follow this PCB layout diagram and the photo at left to build the unit. Note that LED1 and power switch S1 are mounted on the underside of the board.

The output of the input amplifier is full-wave precision-rectified before the signal is applied to the RMS core. RMS conversion essentially squares, averages and then takes the square root of the value. Averaging is done using capacitor C_{AV} at pin 5 (ie, the 47µF and 100µF capacitors connected in parallel on the circuit).

The output amplifier buffers the output from the RMS core and allows for optional low-pass filtering to be performed via external capacitor C_F (10µF in our circuit), which is connected across the feedback path of the amplifier. This additional filtering stage helps reduce any output ripple that is not removed by averaging capacitor C_{AV}.

Power supply

Power for the circuit is provided by a 9V battery, fed via reverse-polarity protection diode D3 and switch S1. A 100µF capacitor bypasses the resulting nominal 8.7V supply. In addition, the supply rails to IC2 are decoupled using 100nF capacitors, one across the Vcc supply and another across Vcc/2.

Battery voltage indication is provided by LED1 connected in series with 5.6V zener diode ZD1 and a 2.2kΩ resistor. When the battery is fresh there will be an 8.7V supply. With a nominal 1.8V voltage drop across the LED and 5.6V across ZD1, that leaves 1.3V across the 2.2kΩ resistor and so there is a 590µA LED current, which gives a relatively bright LED (a high brightness LED is specified).

As the battery goes flat, the battery voltage decreases and so the current through the LED diminishes. The LED current drops to near zero with a 7.4V supply, which is about the end point for the battery as far as this circuit is concerned.

Construction

The assembly is straightforward, with most of the parts mounted on a PCB coded 04203151, measuring 86 × 130mm. This is housed in a UB1 plastic case (see photos) and a second PCB, coded 04203152 (88 × 26mm) is slid into the side pillars of this box to provide the necessary isolation between the mains wiring and the low-voltage measurement circuitry.

A third PCB coded 04203153 (90 × 151mm) is used as the front panel. It takes the place of the original plastic lid and is screen printed and predrilled. All three of the PCBs are available from the *EPE PCB Service*

Fig.4 shows the parts layout on the project's PCB. Most of the components are mounted on the top side, the exceptions being LED1 and power switch S1, which are mounted on the underside.

Begin construction by installing the resistors – we recommend checking each one with a multimeter before installing it on the PCB, as some colours can be difficult to read.

Diodes D1-D3 and zener diode ZD1 can go in next. Be careful not to get these mixed up and make sure they are installed with the correct orientation.

Follow with the two ICs, again taking care to ensure that they are orientated correctly (they go in with their notched ends towards the battery holder). Note that IC1 is the TLE2071, while IC2 is the AD736. You can either solder them directly to the PCB or install them using IC sockets.

The next step is to fit PC stakes at the Common (COM), AC and DC output connection pads (these stakes are later wired to the three output terminals). Once they're in, install the capacitors. The MKT and ceramic types can be installed either way around, but the electrolytic types are polarised and must be oriented as shown on Fig.4. Note that the positive leads are longer.

VR1 and VR2 are next and must be fitted with their adjustment screws positioned as shown. VR1, a 50kΩ trimpot, could be marked as 503, while VR2, a 100kΩ trimpot, could be marked as 104. *Don't get them transposed!*

The battery holder and current transformer can now be mounted in place. The battery holder is held using three No.4 × 6mm self-tapping screws.

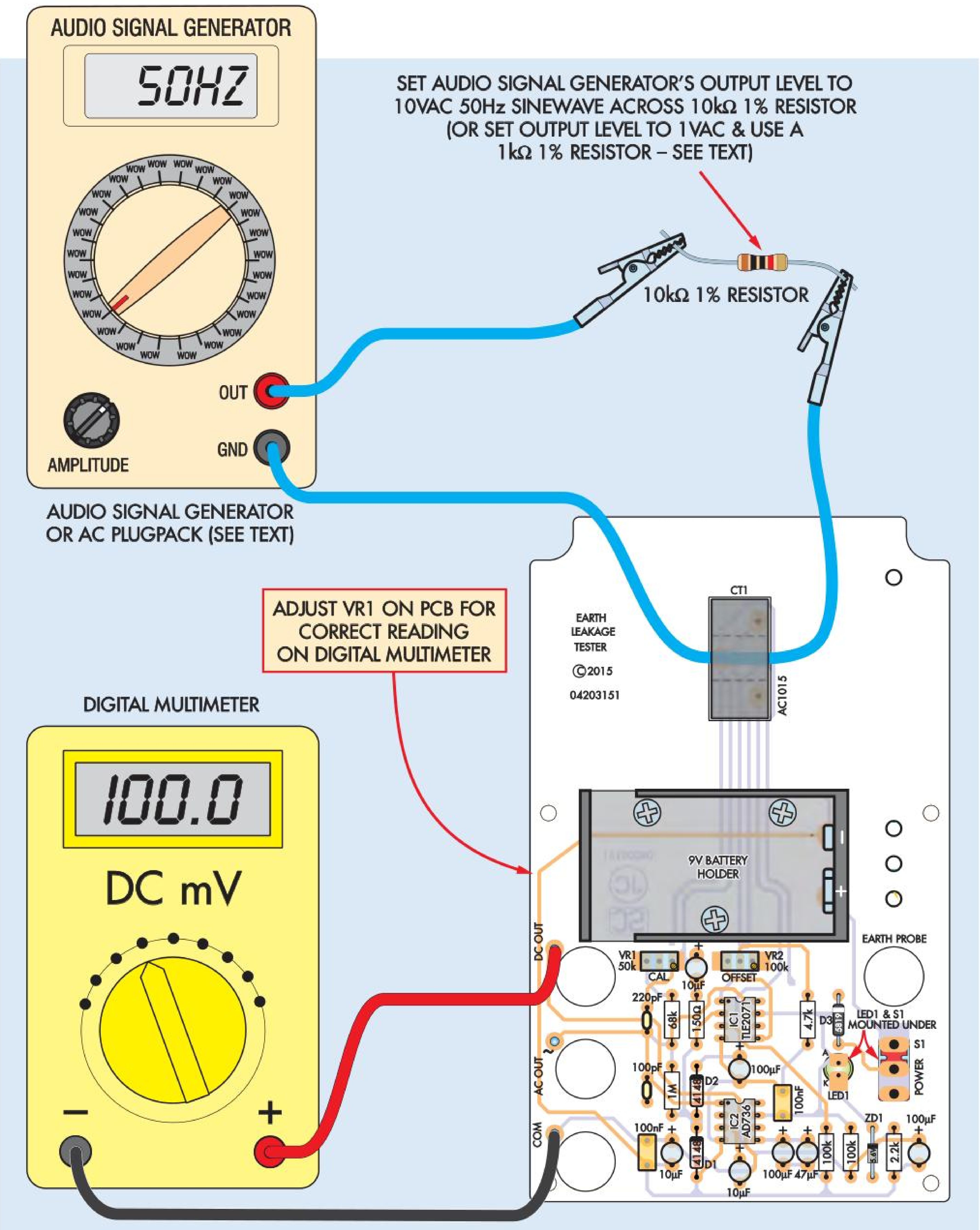

AUDIO SIGNAL GENERATOR
50HZ
WOW
OUT
GND
AMPLITUDE
AUDIO SIGNAL GENERATOR OR AC PLUGPACK (SEE TEXT)
SET AUDIO SIGNAL GENERATOR'S OUTPUT LEVEL TO 10VAC 50Hz SINEWAVE ACROSS 10kΩ 1% RESISTOR (OR SET OUTPUT LEVEL TO 1VAC & USE A 1kΩ 1% RESISTOR – SEE TEXT)
10kΩ 1% RESISTOR
ADJUST VR1 ON PCB FOR CORRECT READING ON DIGITAL MULTIMETER
DIGITAL MULTIMETER
100.0
DC mV
–
+
CT1
EARTH LEAKAGE TESTER
©2015
04203151
AC1015
9V BATTERY HOLDER
EARTH PROBE
DC OUT
AC OUT
COM
VR1 50k
CAL.
10µF
VR2 100k
OFFSET
220pF
68k
150Ω
IC1 TLE2071
4.7k
D3
5819
LED1 & S1 MOUNTED UNDER
S1
POWER
A
K
LED1
100pF
1M
4148
D2
100µF
IC2 AD736
100nF
ZD1
100µF
100nF
10µF
4148
D1
10µF
100µF
47µF
100k
100k
5.6V
2.2k

Fig.5: this diagram shows the set-up used for the calibration procedure. It involves passing a 1mA current through the current transformer and then adjusting VR1 for a 100mV reading on the multimeter (see text overleaf for further details).

Underside components

All that remains now to complete the PCB assembly is to install LED1 and switch S1. These both go on the underside of the PCB. Install the switch first, then fit a single nut to its mounting thread and wind it all the way up to the switch body.

Don't solder the LED in place though. For the time being, simply push it down onto the underside of the PCB, making sure that its anode lead is oriented as shown. Its leads will be soldered later, when the front panel is fitted to the PCB.

Adjustment and calibration

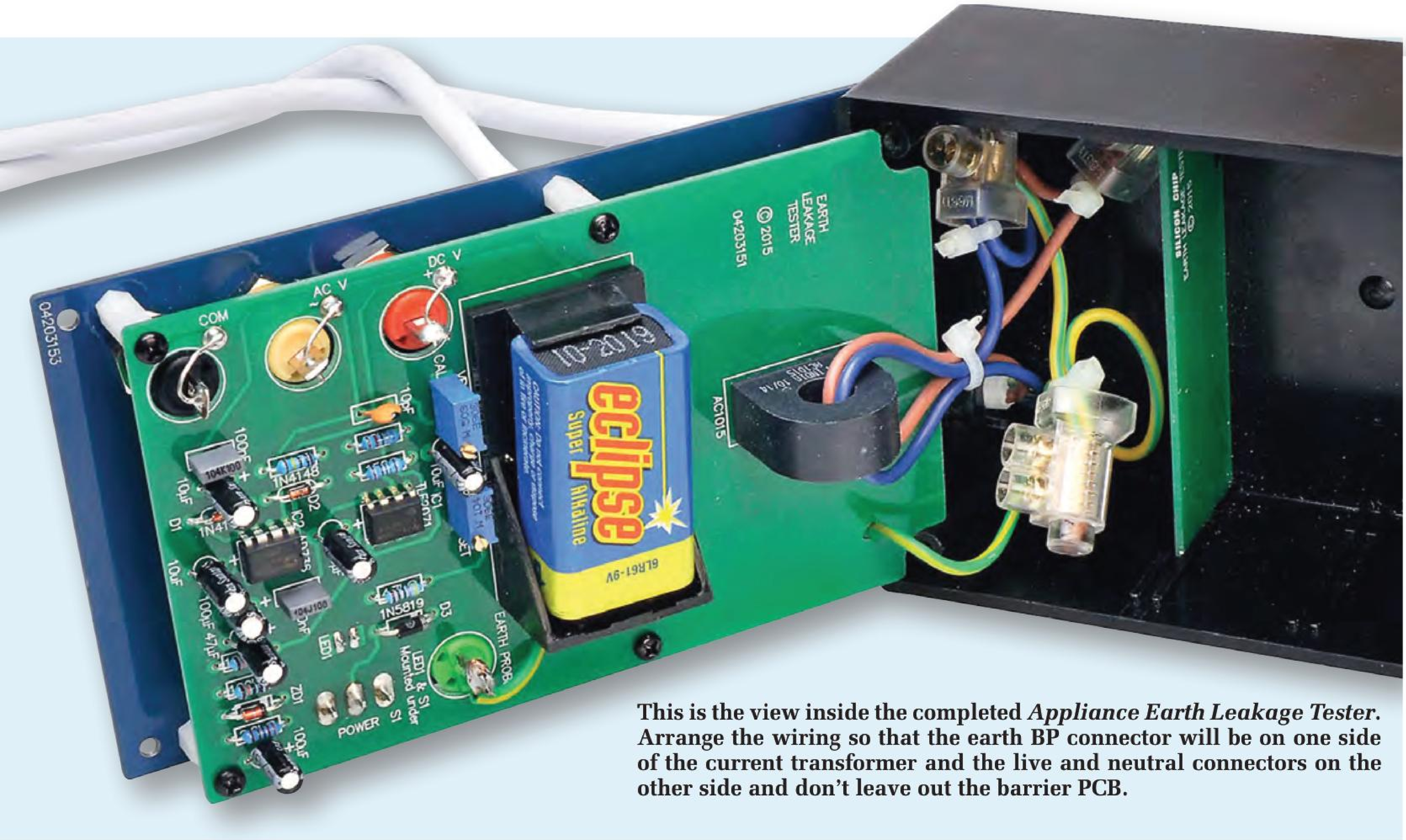
Now for the test and calibration procedure. First, insert a 9V battery into the holder and switch on power. Check that there is power (approximately 8.7V) between pins 7 and 4 of both IC1 and IC2. Pin 3 of IC1 and pins 2 and 8 of IC2 should be at half the supply. This voltage can be measured with the multimeter's negative probe connected to the 0V rail.

The next step is to adjust the DC output offset at pin 6 of IC1. That's done by connecting your multimeter (set to measure DC mV) between the COM and AC V terminals on the PCB and adjusting VR2 so that the reading is as close to 0mV DC as you can set it. For example, we were able to adjust our prototype to obtain a reading which flickered around 0.05mV.

Important note: even though you are measuring between the AC V and COM terminals on the PCB, you are adjusting for a minimum DC voltage and you should get a reading which is a fraction of a millivolt DC. If you accidentally switch to the AC millivolt range on the DMM, you are likely to get a much higher reading because the circuit will be reacting to stray hum fields.

The next step involves passing a current of 1mA (or thereabouts) through the transformer and you can do this with a sinewave signal generator that can deliver a 10VAC signal at 50Hz.

The set-up is shown in Fig.5 and uses a series 10kΩ resistor to provide the 1mA current via a single wire loop through the current transformer. First, connect the signal generator probes as shown and adjust the level for 10VAC RMS across the 10kΩ resistor, as measured with a multimeter. That done, connect your multimeter (set to measure DC mV) between the DC V and COM PC stake terminals on the PCB, apply the 1mA signal through



This is the view inside the completed *Appliance Earth Leakage Tester*. Arrange the wiring so that the earth BP connector will be on one side of the current transformer and the live and neutral connectors on the other side and don't leave out the barrier PCB.

the toroid and adjust VR1 for a reading of 100mV DC.

If your signal generator cannot deliver 10VAC across the 10kΩ resistor, just set it to the maximum available and note the signal level reading. Then adjust VR1 for a reading that corresponds to the current flowing through the 10kΩ resistor. So if, for example, your signal generator can develop a 3VAC signal across the 10kΩ resistor, adjust trimpot VR1 so that the multimeter reads 30mV when connected to DC V and COM.

If your signal generator only delivers 1VAC or thereabouts, a 1kΩ 1% resistor should be used instead of the 10kΩ resistor to provide the required 1mA calibration current. The calibration accuracy needs to be within ±5%.

If you don't have an audio signal generator, you can do the calibration with an AC plugpack. For example, we found a 9VAC plugpack in the junkbox and measured its output across a 10kΩ resistor. It was 10.45V. In that case, 10.45V across the 10kΩ resistor would result in a current of 1.045mA through the toroid and you would adjust VR1 for a reading of 104.5mV DC.

Final assembly

With the calibration completed, you can finish the PCB and front panel assembly and install it in the case.

Begin by fitting the red, black, yellow and green shrouded banana sockets to the front panel PCB and secure them with the supplied nuts. Do not over-tighten these nuts; if you do, the plastic thread will be stripped. The red socket is for the DC output, the yellow for the AC output, the black for common and the green for the earth probe connection.

Now attach four M3 × 15mm tapped spacers to the PCB's mounting holes using M3 × 6mm screws, then fit the front panel in position over switch S1 and secure it in place using four M3 x 6mm screws into the spacers. Once it's secure, push LED1 into its hole in the front panel, then solder it in place.

Next, wind the switch nut up so that it contacts the underside of the front panel, then fit a nut onto the top of the switch and tighten it down. Finally, complete the assembly by soldering wires between the three PC stakes and their adjacent banana sockets, as shown on Fig.4 and Fig.6.

Preparing the case

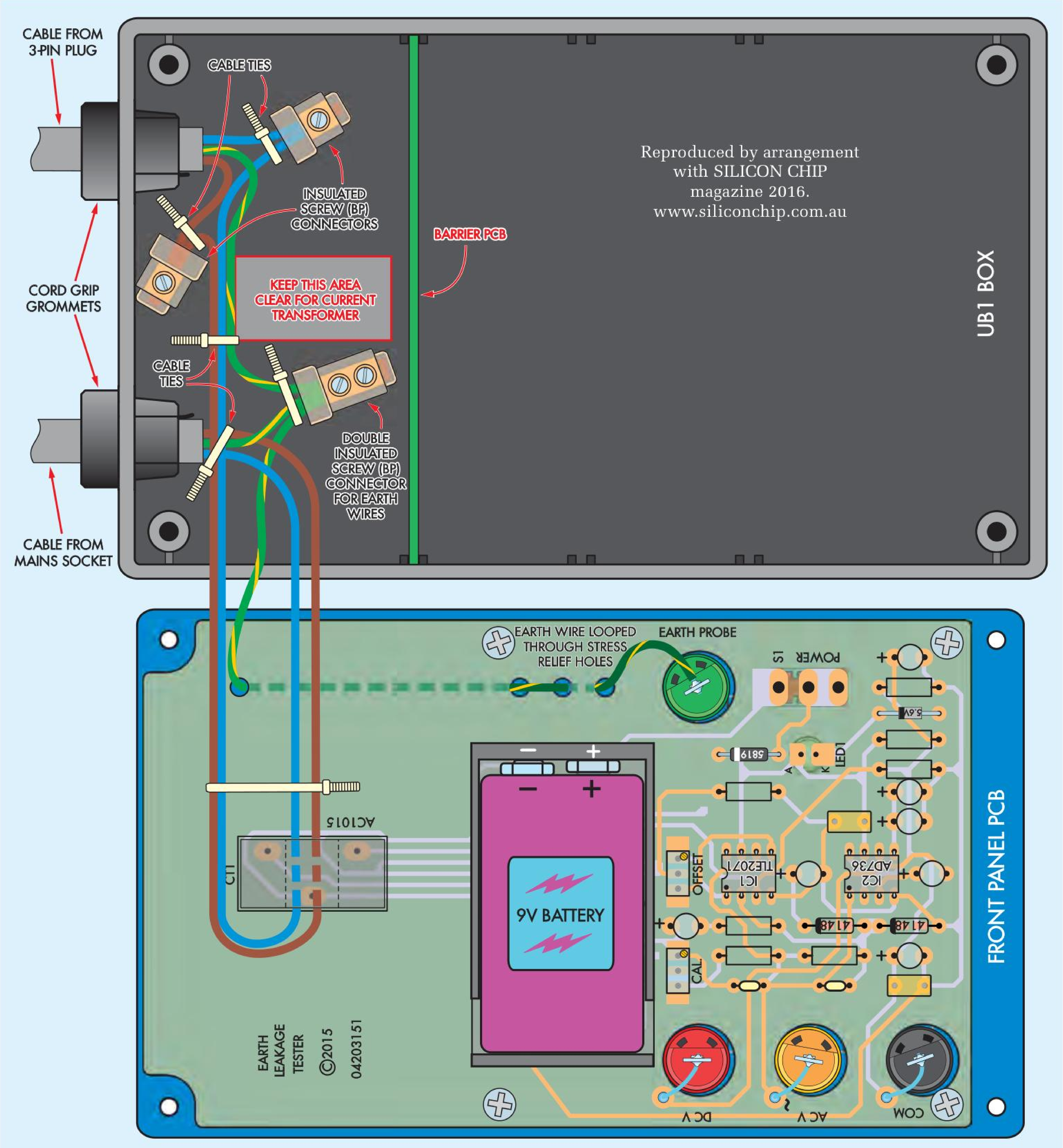
The first job with the case preparation is to trim the internal ribs on the ends of the UB1 case, as they prevent the front panel from sitting down onto the four corner pillars. These ribs can be cut down using sharp side-cutters or a hobby knife. You then need to drill and shape holes for two cord-grip grommets in the top end of the box. As shown in the photos and Fig.6, these grommets are used to secure a mains plug lead and a mains socket lead.

It's important that these two holes be shaped so the grommets (and the cords) are securely captured in the panel. Fig.7 shows the hole template and a photocopy of this can be sticky-taped to the box and the hole outlines scribed out with a sharp hobby knife. The two holes can then be drilled, reamed and carefully filed to shape (don't just drill round holes; they will not secure the grommets correctly).

Note: do not use cable glands; the plastic nuts come undone too easily to ensure secure clamping.

Next, cut a 1.5-metre (or longer) mains extension cable in half and strip about 150mm of outer insulation from each end, then feed them through their case holes and clamp them in place using the cord-grip grommets. **Check to make sure that they are securely clamped – it must not be possible to pull the lead out from the grommet.**

Note also that there are different types of cord grip grommet. The most common is only suitable for use with a thin panel (typically aluminium or steel). The grommets specified for the


CABLE FROM 3-PIN PLUG
CABLE TIES
INSULATED SCREW (BP) CONNECTORS
BARRIER PCB
KEEP THIS AREA CLEAR FOR CURRENT TRANSFORMER
CORD GRIP GROMMETS
CABLE TIES
DOUBLE INSULATED SCREW (BP) CONNECTOR FOR EARTH WIRES
CABLE FROM MAINS SOCKET
UB1 BOX
EARTH WIRE LOOPED THROUGH STRESS RELIEF HOLES
EARTH PROBE
S1
POWER
5.6V
5819
LED1
A
K
AC1015
CT1
9V BATTERY
OFFSET
IC1
TLE2071
IC2
AD736
4148
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CAL
EARTH LEAKAGE TESTER
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04203151
DC V
AC V
COM
FRONT PANEL PCB

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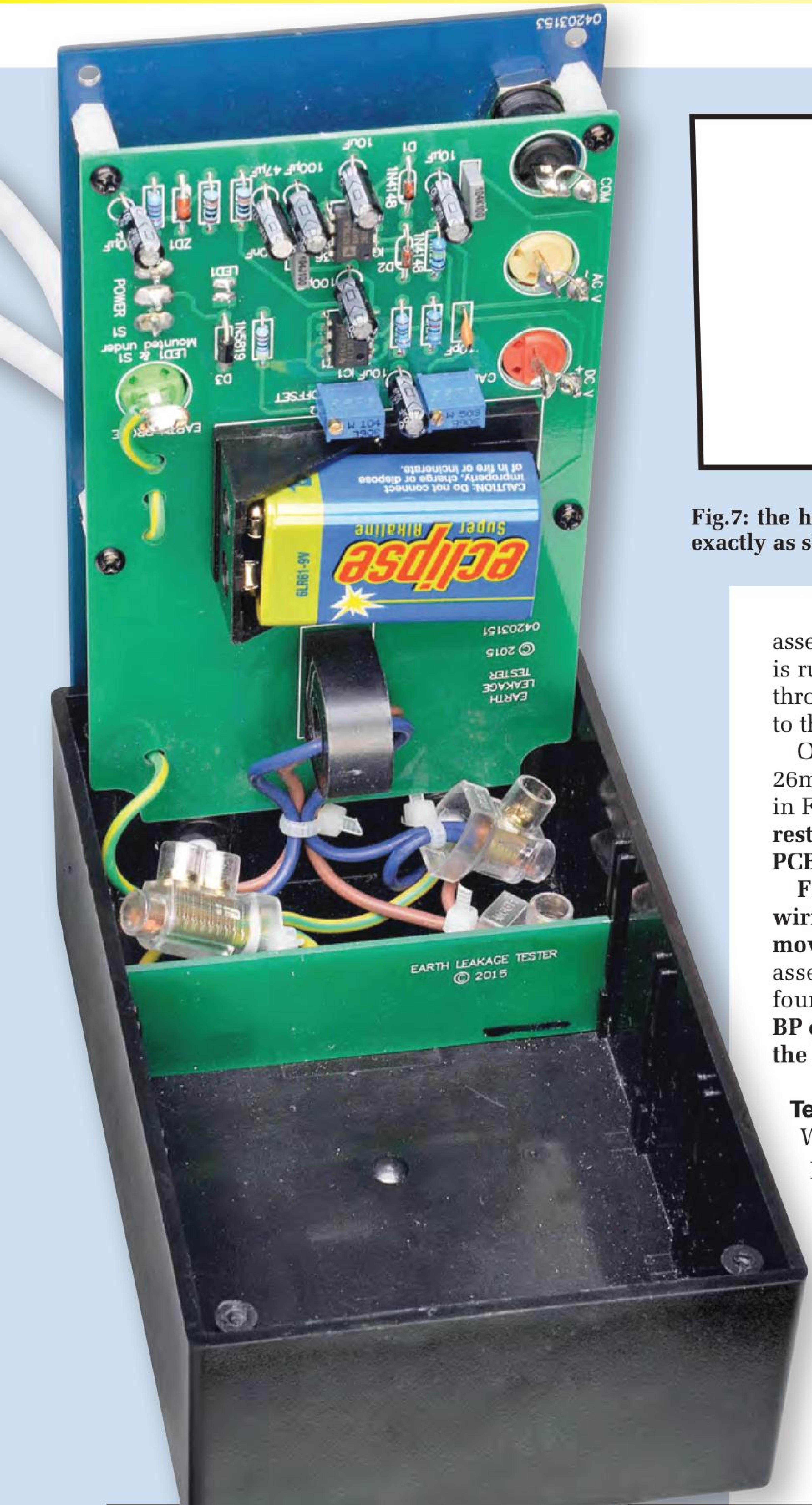
Fig.6: follow this wiring diagram to complete the *Appliance Earth Leakage Tester*. Make sure that the BP connectors are all securely attached to their respective wires and be sure to use a double-screw BP connector for the earth leads. Once the wiring is completed, secure the leads with cable ties as shown.

Appliance Earth Leakage Tester are for thicker panel material, in this case 3mm – see parts list for specified type.

Now trim and strip the mains wires, twisting them together and terminating them in BP (blue point) connectors – see Fig.6. **Use one-screw BP connectors for the live and neutral leads and a double-screw BP connector for the earth wires and make sure all connections are secure.**

As shown in Fig.6, keep the live and neutral leads from the plug fairly short and make sure that the three earth wires are secured by both screws in the mains connector.

As shown in Fig.6, the live and neutral wires from the socket lead are looped through the current transformer (CT1) before going to their respective mains connectors. Note the area that needs to be kept free from any BP connectors, to leave room for the current transformer when the PCB/front panel



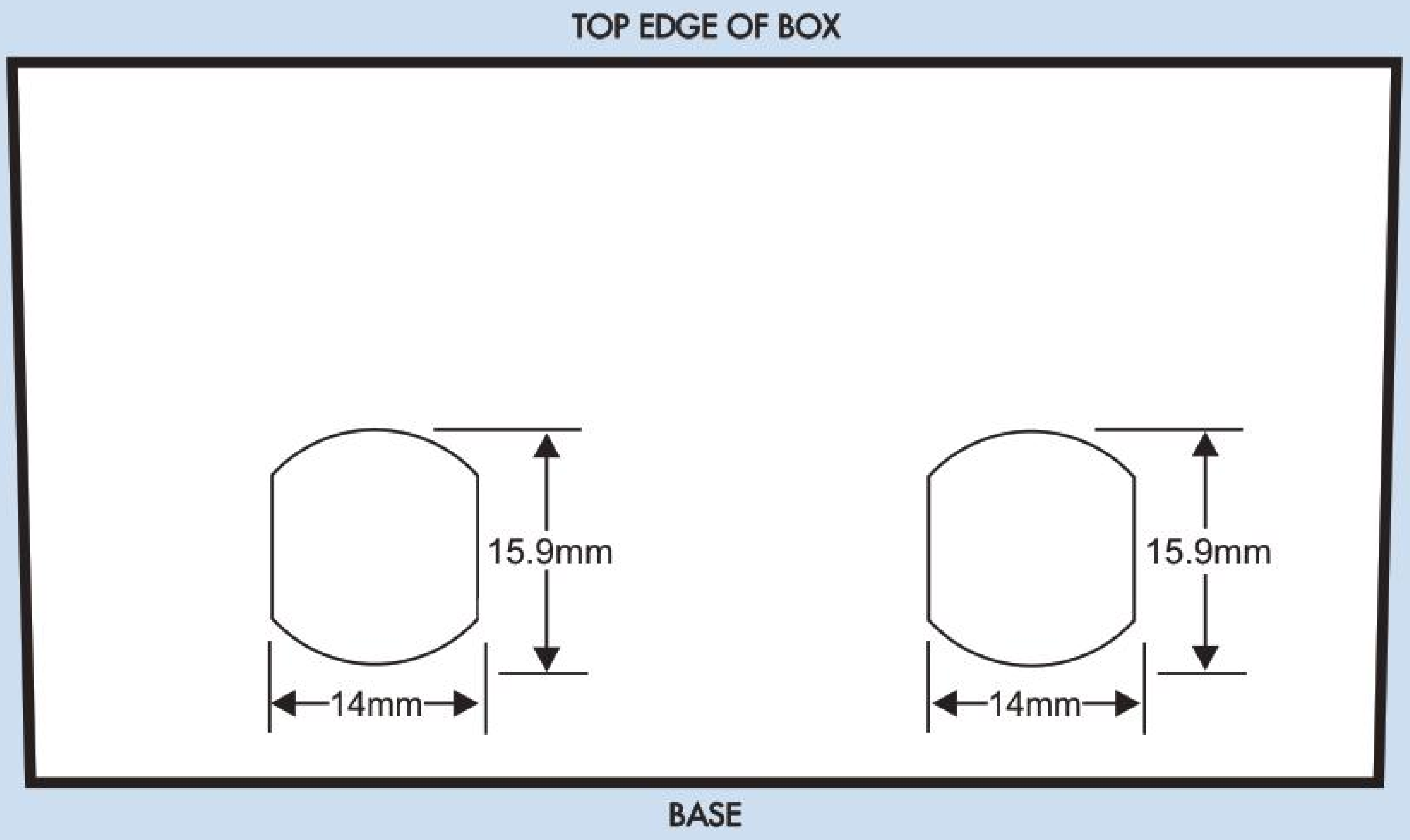


Fig.7: the holes for the two cord-grip grommets must be profiled exactly as shown, to ensure they grip they mains cords securely.

assembly is fitted in position. Note also that an earth wire is run from the double-screw BP connector and is looped through strain relief holes in the main PCB and connected to the earth banana socket.

Once the wiring has been completed, slide the 88 × 26mm barrier PCB into the side pillars in the box, as shown in Fig.6. **This barrier isolates the mains wiring from the rest of the (low-voltage) circuitry. Do not leave the barrier PCB out – it's an important safety measure.**

Finally, fit cable ties where indicated to hold the mains wiring together. These will prevent individual wires from moving and possibly coming adrift. The PCB/front panel assembly can then be fitted in place and secured using four corner mount screws. **Be sure to position the earth BP connector to one side of the current transformer and the live and neutral connectors to the other side.**

Testing appliances

When testing appliances, the condition of the mains plug, lead and earth connection should first be checked. Make sure that mains wires are not frayed, repaired with insulation tape, broken or exposed.

Appliances that have metal parts earthed via the mains plug should also initially be checked using a digital multimeter (DMM). The DMM is used to check the resistance between the earth pin on the mains plug and any exposed metal on the appliance and the measured resistance should be 1Ω or less.

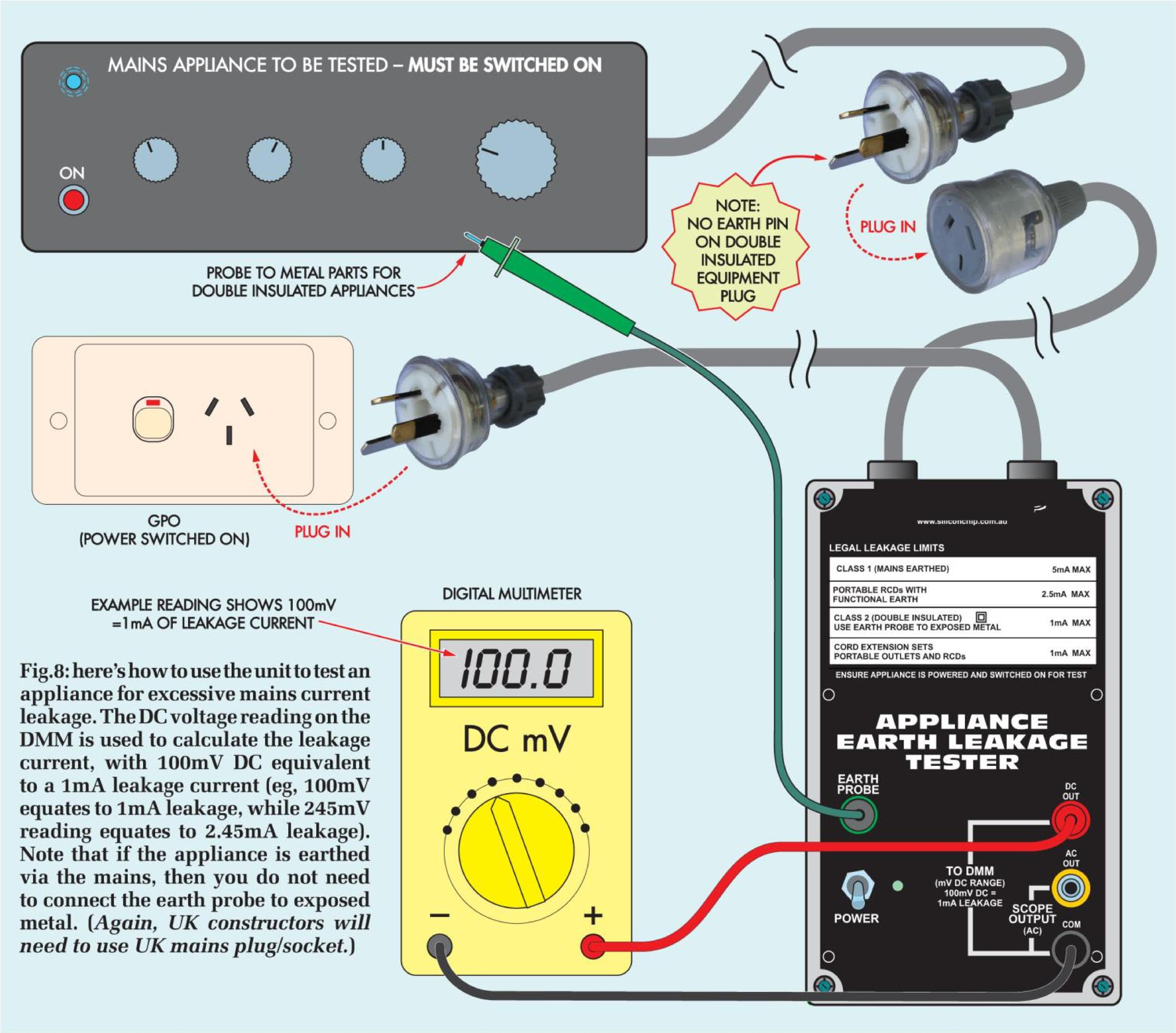
Note that before taking any readings, the DMM should be checked for a 0Ω reading with its probes

Why not use a current clamp meter?

An obvious question when making leakage current measurements is why not just use an extension cord that has its live and neutral leads separated from the earth lead, so that a clamp meter can simply measure the differential live and neutral current?

Apart from the legalities involved in using a 'doctored' extension cord, the problem is that you would need a specialised clamp meter that can measure current down in the mA range with at least 5% accuracy. However, most clamp meters are unsuitable as they are designed for high currents, with typical ranges of 40A and 400A, and have insufficient resolution or accuracy for a 1mA reading (let alone 5% accuracy).

Clamp meters with a 40A range and a 4-digit display have only 10mA resolution, for example.


MAINS APPLIANCE TO BE TESTED – **MUST BE SWITCHED ON**
ON
PROBE TO METAL PARTS FOR DOUBLE INSULATED APPLIANCES
NOTE: NO EARTH PIN ON DOUBLE INSULATED EQUIPMENT PLUG
PLUG IN
GPO (POWER SWITCHED ON)
PLUG IN
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–
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CORD EXTENSION SETS PORTABLE OUTLETS AND RCDs 1mA MAX
ENSURE APPLIANCE IS POWERED AND SWITCHED ON FOR TEST
APPLIANCE EARTH LEAKAGE TESTER
EARTH PROBE
DC OUT
AC OUT
TO DMM (mV DC RANGE) 100mV DC = 1mA LEAKAGE
SCOPE OUTPUT (AC)
POWER
COM

Fig.8: here's how to use the unit to test an appliance for excessive mains current leakage. The DC voltage reading on the DMM is used to calculate the leakage current, with 100mV DC equivalent to a 1mA leakage current (eg, 100mV equates to 1mA leakage, while 245mV reading equates to 2.45mA leakage). Note that if the appliance is earthed via the mains, then you do not need to connect the earth probe to exposed metal. (*Again, UK constructors will need to use UK mains plug/socket.*)

shorted together. If it's not close to 0Ω, then the probe tips, the banana plugs at the ends of the probe leads and the DMM's input sockets may require cleaning. Inserting and removing the banana plugs in the sockets a few times is a good way of cleaning the contacts.

Fig.8 shows how the unit is used to test an appliance. The appliance is plugged into the tester's socket lead, while the tester's mains plug is plugged into a mains wall socket. The wall socket and the appliance itself are then switched on and a DMM used to take the reading.

Note that switching the appliance on may be a multi-step process; if the appliance is in a stand-by mode, the measurement will not be valid as some of the circuitry may not be powered. In many cases, it will be necessary to apply power and then press the on/off pushbutton, either on the unit itself or on its remote control.

The DC voltage reading on the DMM is then used to calculate the leakage current, with 100mV DC equivalent to a 1mA leakage current. So, for example, a 245mV reading equates to a leakage current of 2.45mA.

If the appliance is earthed, then you do not need to connect the earth probe to exposed metal, but you must do so for correct readings on double-insulated appliances. Note that some metal parts may be painted or anodised and you may need to scrape away some of the coating so that a proper connection can be made. A case screw is often a good place to make a connection.

Using a scope

The oscilloscope waveform on the next page shows the earth leakage from a double-insulated set-top box, as measured at the tester's AC output. This set-top box has a switch-mode power supply that includes electromagnetic interference (EMI) bypass capacitors that are grounded back to its metal case.

The earth leakage waveform shows the higher-frequency components within the 50Hz envelope and these extend far beyond 20kHz. Note that the leakage is not a sinewave, but one that reflects the high crest current flow typical of switch-mode power supplies.

We measured the RMS amplitude of this waveform on the scope, along with the DC voltage reading (green trace) and they were almost identical.

Appliance Insulation Tester or Appliance Earth Leakage Tester: *Which One Should Be Used?*

There are two types of testers described in the Australian Standards *AS/NZS3760 – In-service Safety Inspection And Testing Of Electrical Equipment.* These are an appliance insulation tester and an appliance earth leakage tester.

We published a suitable insulation tester design last month and this applies a DC voltage (either 250V or 500V) between the live/neutral pins and the appliance earth and measures any leakage current flow between them. The problem is that if the device being tested contains relays or solid-state mains switching, the applied voltage may not reach some of the internal circuitry, which could possibly have significant earth leakage and thus this test could miss a potentially hazardous fault.

By contrast, this earth leakage tester measures the current flow when 230VAC mains is applied to the unit. Since it is operating normally, any internal switching can be activated and thus mains voltage can reach all of its circuitry and its earth leakage can be checked more thoroughly.

However, the AC waveform peak of around 325V DC is lower than 500V and thus this test may not pick up leakage due to marginal insulation which could cause problems during power surges (eg, in a storm). The peak voltage is also relatively brief, so any leakage which occurs only at the highest voltages could be underestimated.

Ideally, you'll use both tests to check an appliance and you certainly should do an earth leakage test on any equipment with a remote control or stand-by mode.

Note that in either case, when testing earthed equipment it's necessary to first verify that its earth connection is good, as explained in the text.

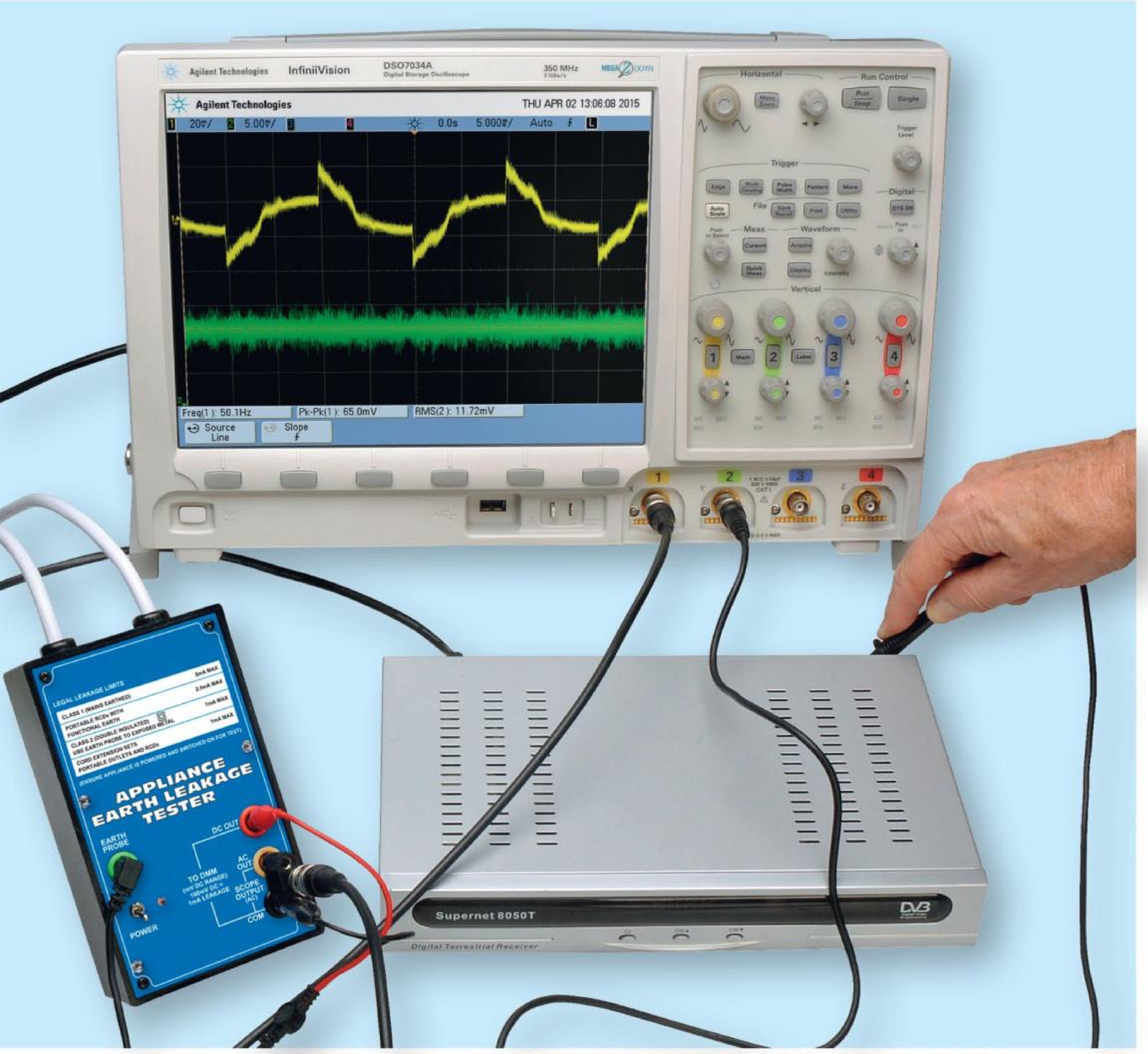

Fig.9: using the *Appliance Earth Leakage Tester* with a scope. In this case, the yellow scope waveform shows the earth current leakage from a double-insulated set-top box.

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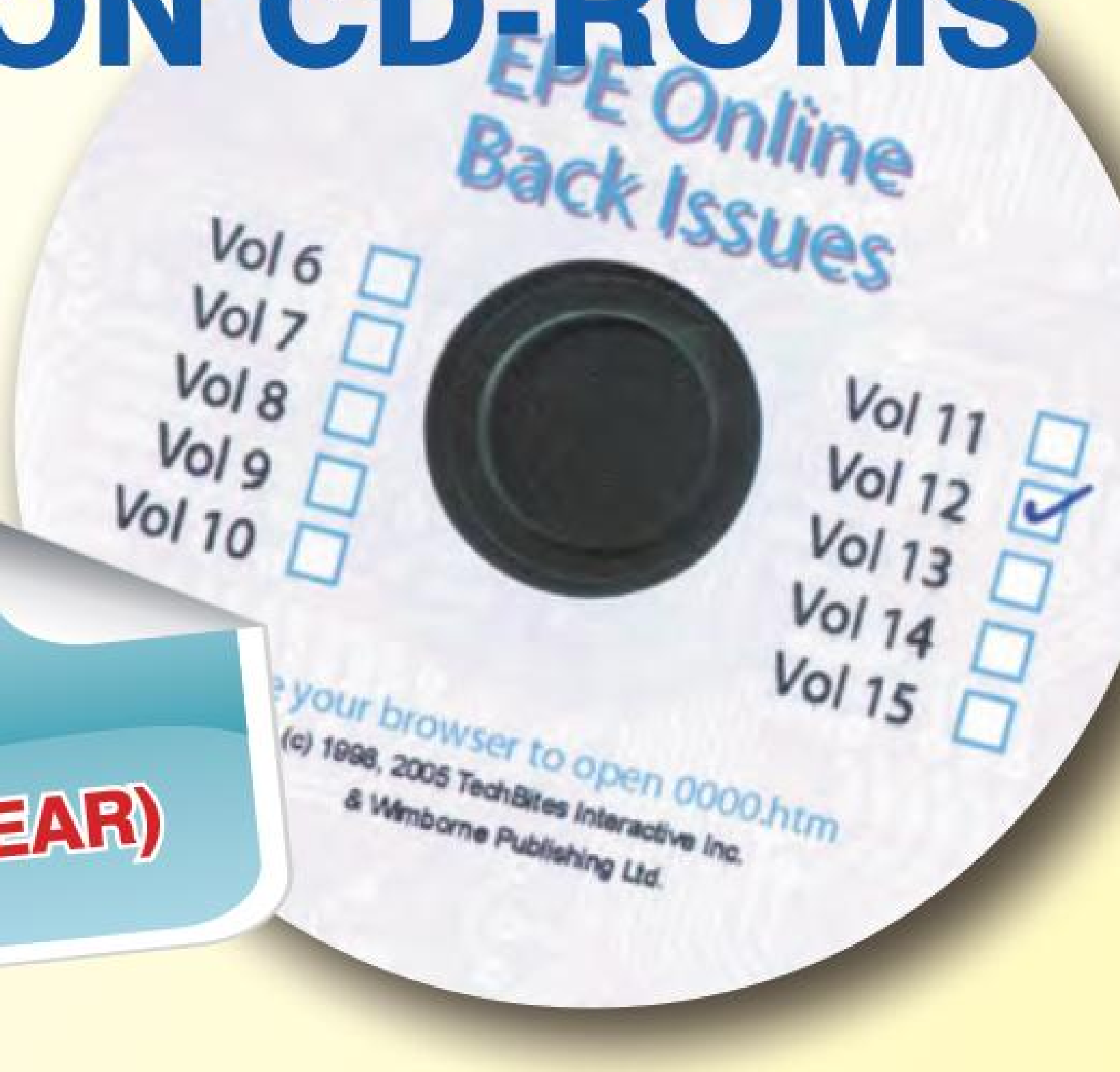

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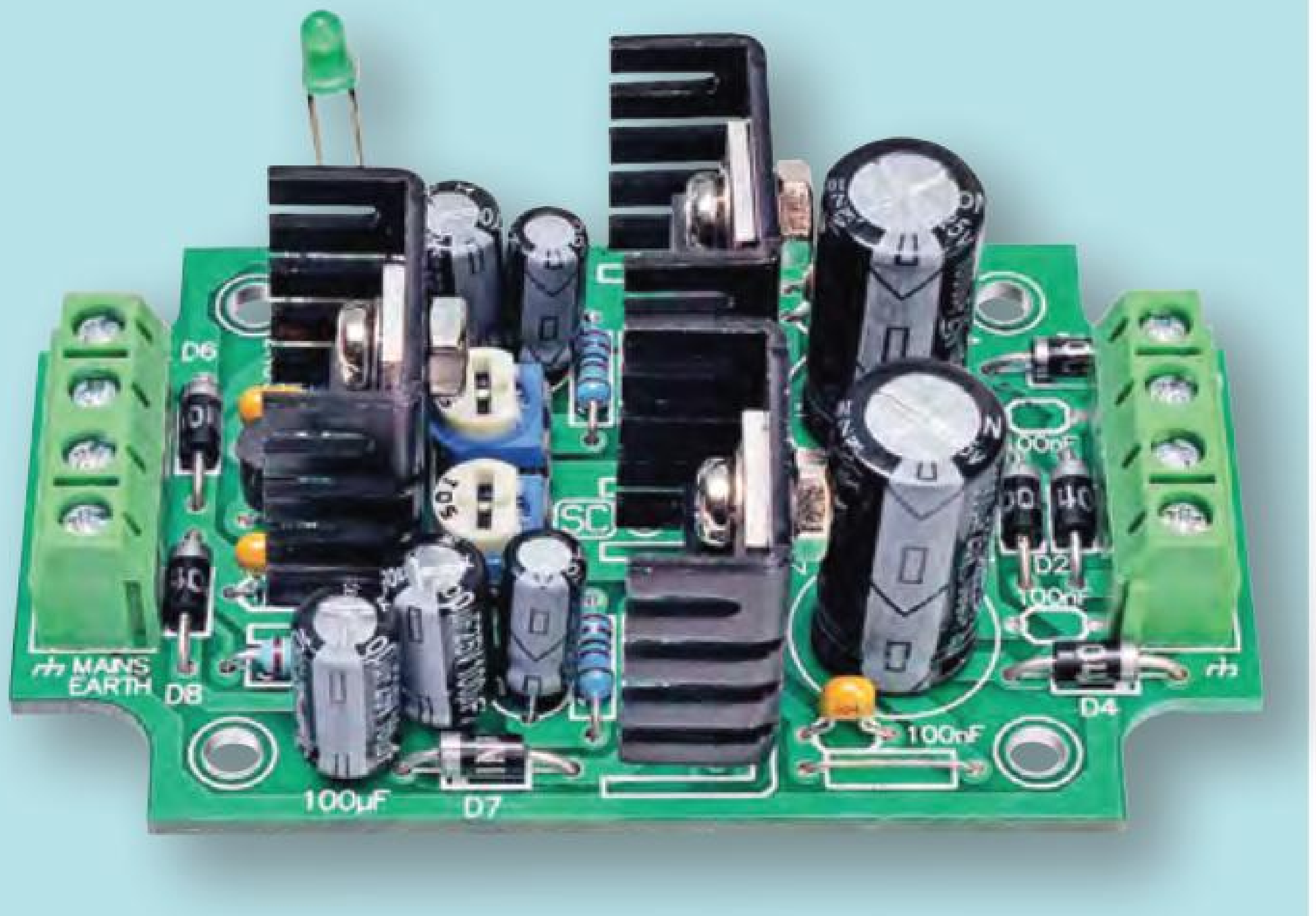


By Jim Rowe and Nicholas Vinen

This is our most flexible linear regulator board yet. It has provision for four outputs: adjustable positive and negative outputs and two fixed positive outputs of 5V and 3.3V. It can be fed from an AC plugpack, small transformer or DC supply with balanced outputs.

THIS MODULE was initially designed to power the *Balanced Input Attenuator* project elsewhere in this issue, but it can also be used to power a wide variety of circuits. It can supply balanced rails for op amps and comparators as well as multiple low-voltage rails to power microcontrollers and digital logic ICs.

A typical configuration with four outputs might be: +15V, –15V, +5V and +3.3V. These can all come from the same transformer, as long as the current requirements are modest. It can fit into a small jiffy box for low-current applications and this can even be mounted on the back of a (large) plugpack. Alternatively, there are four mounting holes, so it can be held in a larger case by tapped spacers.

It's designed to run from an AC plugpack or small AC transformer, but a DC supply can also be used provided you don't need a negative output voltage. Ideally, if a transformer is used, it should have a centre tap although this is not required and indeed most AC plugpacks lack a centre tap connection.

The input and main output connections are made via terminal blocks at either end of the PCB, while the 3.3V, 5/6/9/12V and GND terminals are via a polarised header. There's an on-board LED to indicate that power is present.

This new design has quiet outputs which are more suitable for powering sensitive audio gear. In addition, since this regulator is adjustable, the two main output voltages can be accurately set without changing any components.

Features and specifications

Output voltages: 1.3V to 22V, –1.3V to –22V plus either 12V, 9V, 6V or 5V + 3.3V*

Continuous output current: typically 200mA+ per output, depending on voltages

Peak output current: up to 1.5A on adjustable outputs, 1A/250mA for fixed outputs

Output ripple: typically <1mV RMS on all outputs up to 250mA load

Line regulation: <2mV/V (main outputs), <1mV/V (auxiliary outputs)

Load regulation: <20mV/A

Transient response (1A load step): 500mV drop, 400mV overshoot, 200ms recovery

Quiescent current: ~40mA (AC supply), ~25mA (single polarity DC supply)

Protection: short-circuit, over-current, over-temperature, reverse polarity (with DC supply)

** Main positive output must be at least 2V higher than auxiliary output voltage*

Different configurations

This design has provision for four regulators as noted above; however, if you don't need four different voltages you can leave some components off to save time and money.

Since it's common to need two or three regulated supply rails, we're providing a few different options for building the module:

- Version A: this deluxe version includes all four outputs, two adjustable and two fixed, plus a power LED. It can run off single, dual or centre-tapped transformer secondaries.
- Version B: like Version A, this one has positive and negative adjustable outputs but does not include the two extra fixed positive regulators for circuits where they are not required.
- Version C: similar to Version B, but the output voltages are set by fixed resistors and it will only run from a transformer with a single secondary winding. This is the version used

to supply the ±15V rails for the *Balanced Input Attenuator* from a 17VAC plugpack.

- Version D: similar to Version A (deluxe) but without the negative adjustable regulator and associated components. Thus, it has three outputs, all positive: one adjustable and two fixed. It can run from an AC or DC supply, including batteries, DC plugpacks and in-line switch-mode supplies.
- Other combinations are possible and, for example, it would be possible to modify Version D so that it has a full-bridge rectifier at its input, which might be handy if you want to run it from an AC plugpack (ie, with a single secondary winding). All four versions can be built using the same PCB.

Voltage limitations

There are many different combinations of voltages that you can get from this board, but there are also a few restrictions. These apply mainly to the two auxiliary outputs, which would normally be +5V and +3.3V, but there are some other options.

The first restriction is that the main auxiliary output (normally 5V), which can deliver 1A, must be at least 2V less than the positive adjustable output. **If you want to have a 6V, 9V or 12V output instead of 5V, it's simply a matter of swapping this fixed regulator for one with a different output voltage. However, the 2V headroom is still required.**

Also, note that any current drawn from either auxiliary output reduces the maximum available from the main positive adjustable output.

Note that if you choose to change the 5V output to a higher voltage, you will lose the 3.3V output as the specified regulator will not withstand a higher input voltage. You can also omit the 3.3V regulator if you don't need that output.

Current capability

While the two adjustable outputs are capable of delivering peak currents of up to 1.5A, in practice, heat dissipation will limit the continuous current delivery to a fraction of this. Similarly, the higher-voltage fixed output is capable of 1A, but it too is normally dissipation-limited. The 3.3V output has no such limitation since it is only rated at 250mA.

How much current you'll get from this board depends mainly on the output voltages and the voltage(s) you're feeding in. In most cases, we expect constructors will be running it from a transformer (including AC plugpacks) and selecting the right transformer for maximum current and to avoid loss of regulation.

Transformer selection

Having figured out what output voltages you need and how much current is required by the circuit it's going to power, use the following procedure to select a transformer or power supply.

Let the highest positive voltage that's required be Vp(max) and the total current required from all positive outputs be Ip(sum). Similarly, let the magnitude of the negative output voltage be Vn and the required negative current be In.

For a transformer with a single secondary, the ideal voltage is whichever of these two results is higher:

$$V1 = (Vp(max) + 3.5V + Ip(sum) \text{ x } 20) \text{ x } 0.7$$
$$V2 = (Vn + 3.5V + In \text{ x } 20) \text{ x } 0.7$$

Whereas for a transformer with two secondaries or a single centre-tapped secondary, use:

$$V1 = (Vp(max) + 3.5V + Ip(sum) \text{ x } 10) \text{ x } 0.7$$
$$V2 = (Vn + 3.5V + In \text{ x } 10) \text{ x } 0.7$$

For a centre-tapped transformer, double the resulting voltage.

It's unlikely you'll get a result that's a round number, so choose a transformer with the next highest voltage rating. Often, you will find that you need a transformer with the same AC voltage rating as the highest DC output voltage you have selected, eg, a 15VAC transformer is used for ±15V DC outputs.

Now, let the transformer secondary voltage be Vac. To calculate the required transformer VA rating, use the following formula for a transformer without a centre tap:

$$VA = Vac \text{ x } 1.5 \text{ x } (Ip(sum) + In)$$

For transformers with a centre tap, use:

$$VA = Vac \text{ x } 0.75 \text{ x } (Ip(sum) + In)$$

Note that it's generally a good idea to choose a transformer with a somewhat higher VA rating if at all possible. This is not just us being conservative; with a circuit like this, because most of the current will be drawn at the voltage peaks, these calculations will underestimate the I^2R losses in the transformer and so it will get hotter than you might expect. Thus a transformer

Parts List

1 double-sided PCB available from the *EPE PCB Service*, coded 18105151, 76 × 46mm
1 UB5 jiffy box (optional) OR
4 M3 tapped spacers and machine screws for mounting
1 transformer or plugpack to suit required voltages/currents
4 2-way mini terminal blocks, 5.08mm pitch (CON1,CON2)
1 3-way polarised header (CON3)
2 2kΩ mini horizontal trimpots (VR1,VR2)
3 mini flag (6073B-type) heatsinks (for REG1-REG3)
3 M3 × 10mm machine screws and nuts (for mounting heatsinks)
2 grommets to suit input/output cables (optional)

Semiconductors

1 LM317T adjustable positive regulator (REG1)
1 LM337T adjustable negative regulator (REG2)
1 7805T 5V 1A regulator* (REG3)
1 MCP1700-3.3/TO LDO 3.3V regulator (REG4)
8 1N4004 diodes (D1-D8)
1 3mm LED (LED1)

Capacitors

2 2200µF 25V electrolytic
3 100µF 25V electrolytic
2 10µF 25V electrolytic
2 1µF multi-layer ceramic
4 100nF multi-layer ceramic

Resistors (0.25W, 1%)

1 3kΩ 0.5W
1 1.5kΩ
2 1.1kΩ
2 1kΩ
2 100Ω
2 10Ω 0.5W

Notes

(1) Some parts may be omitted, depending on which version is being built.

(2) For wider voltage adjustment range, reduce 1kΩ resistor value. 500Ω trimpots can be used instead for a narrower adjustment range.

(3) *A different 78xx series regulator may be substituted in some cases (see text). In this case, REG4 is not fitted and the 3.3V output is not functional.

Table 1: Power supply configuration options			
Power supply	**Adjustable output(s)**	**Auxiliary output(s)**	**Dropper resistor(s)**
9VAC plugpack or transformer, 4.5VA	±9V 200mA each	5+3.3V* 200mA total	0Ω (wire links)
18VAC centre-tapped transformer, 4.5VA	±9V 200mA each	5+3.3V* 200mA total	0Ω (wire links)
12VAC plugpack or transformer, 6VA	±9V 200mA each	5+3.3V* 200mA total	10Ω 0.5W
12VAC plugpack or transformer, 6VA	±12V 200mA each	5+3.3V** 200mA total	0Ω (wire links)
24VAC centre-tapped transformer, 6VA	±12V 200mA each	5+3.3V** 200mA total	0Ω (wire links)
15VAC plugpack or transformer, 7.5VA	±12V 200mA each	5+3.3V** 200mA total	10Ω 0.5W
15VAC plugpack or transformer, 7.5VA	±15V 200mA each	5+3.3V# 200mA total	0Ω (wire links)
30VAC centre-tapped transformer, 7.5VA	±15V 100mA each	5+3.3V# 300mA total	0# (wire links)
17VAC plugpack or transformer, 8VA	±15V 200mA each	5+3.3V# 200mA total	10Ω 0.5W
36VAC centre-tapped transformer	±15V 200mA each	5+3.3V# 200mA total	10Ω 0.5W
36VAC centre-tapped transformer	±17V 200mA each	5+3.3V## 200mA total	0Ω (wire links)
48VAC centre-tapped transformer***	±24V 200mA each	5+3.3V## 150mA total	0Ω (wire links)
12V DC plugpack or lead-acid battery	+9V, 200mA	5+3.3V* 200mA total	0Ω (wire link)
15V DC plugpack or switchmode supply	+12V, 400mA	5+3.3V** 250mA total	0Ω (wire link)
18V DC plugpack or switchmode supply	+15V, 400mA	5+3.3V# 250mA total	0Ω (wire link)
24V DC plugpack or lead-acid battery***	+12V, 100mA	5+3.3V** 80mA total	0Ω (wire link)

Note: current ratings selected for maximum 2W dissipation per heatsinked TO-220 package; higher currents possible with sufficient airflow. For example, add 50% to all current values for 3W dissipation per package.

* alternative auxiliary output: 6V DC   ** alternative auxiliary outputs: 6V or 9V DC   *** use 1000µF 35V capacitors
# alternative auxiliary outputs: 6V, 9V or 12V DC   ## alternative auxiliary outputs: 6V, 9V, 12V, 15V or 18V DC

with a somewhat higher rating (say 50%) is desirable.

If that all seems too hard, have a look at Table 1. We've done these calculations (plus more explained below) for a number of common configurations. Assuming your needs match up with those, you can simply read the supply options from the table.

Regulator dissipation

Having chosen a transformer, it's now a good idea to check that the regulator dissipation will be reasonable. If it's too high, the regulators could overheat and shut down; this is unlikely to cause any damage, but it will prevent your circuit from working properly.

Let the adjustable positive output voltage be Vp1 and the auxiliary positive voltages be Vp2 (normally 5V) and Vp3 (normally 3.3V). Similarly, the maximum current drawn from each output is Ip1, Ip2 and Ip3. Dissipation can then be approximated as:

$$DISreg1 = (Vac \times 1.4 - Vp1) \times Ip(sum)$$
$$DISreg2 = (Vac \times 1.4 - Vn) \times In$$
$$DISreg3 = (Vp2 - Vp1) \times (Ip2 + Ip3)$$
$$DISreg4 = (Vp3 - Vp2) \times Ip3$$

The results are in watts. As stated earlier, you don't really need to worry about the dissipation of REG4 as it will normally be less than 0.5W. REG1-REG3 can handle about 2W each before you risk them shutting down; more in free air (say 3W) and even more if you have forced air (eg, a fan blowing over the heatsinks).

If using a DC supply, replace the Vac × 1.4 term with the maximum DC input voltage the regulator will experience. For example, if it's being powered from a lead-acid battery which could be charged during use, to be safe, substitute 15V.

It's a good idea to calculate the sum of all four figures, especially if you're planning to put the board in a jiffy box. This will give you an idea of how much heat will be coming off the board. More than a few watts total and the jiffy box will get mighty warm!

Note that if you have had to choose a transformer with a higher-than-ideal voltage rating (due to availability, etc) and the dissipation values for REG1 and REG2 look a little on the high side, the board does have provision to fit a couple of 0.5W dropping resistors before the regulators. These will allow you to reduce the dissipation of each regulator by around one third to one half watt each; not a major reduction, but possibly enough to prevent them from overheating and shutting down. If you do want to do this, calculate the required resistor values as follow:

$$Rp = (Vac \times 1.4 - 3.5 - Vp1) \div (Ip(sum) \times 3)$$
$$Rn = (Vac \times 1.4 - 3.5 - Vn1) \div (In \times 3)$$

Round to the next lowest preferred resistor value. For the *Balanced Input Attenuator* power supply, we had to use a 17VAC plugpack to get the earth connection (ideally we would have used 15VAC). The output voltages are ±15V and the current requirement is around 180mA each. If you do the calculations, you'll come up with 10Ω, which is what we used. The dissipation in REG1 and REG2 then reduces to:

$$DISreg1 = (Vac \times 1.4 - Vp1 - Rp \times Ip(sum)) \times Ip(sum)$$
$$DISreg2 = (Vac \times 1.4 - Vn - Rn \times In) \times In$$

In our case, this leads to a reduction in dissipation of about 0.33W each. Note that this does not change the total dissipation; it merely moves some of it away from REG1 and REG2 and

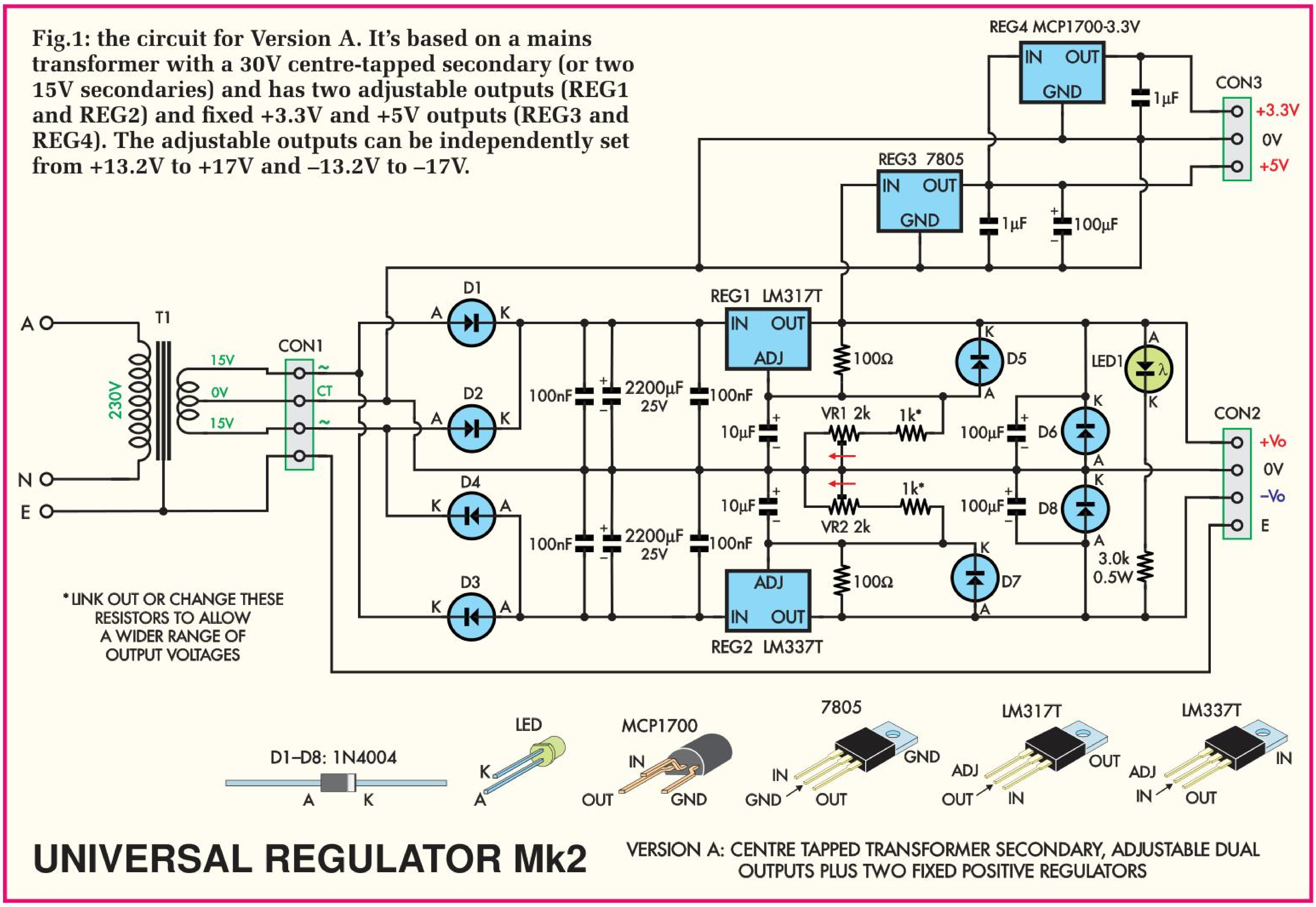


Fig.1: the circuit for Version A. It's based on a mains transformer with a 30V centre-tapped secondary (or two 15V secondaries) and has two adjustable outputs (REG1 and REG2) and fixed +3.3V and +5V outputs (REG3 and REG4). The adjustable outputs can be independently set from +13.2V to +17V and –13.2V to –17V.

REG4 MCP1700-3.3V
IN
OUT
GND
1µF
CON3
+3.3V
0V
+5V
REG3 7805
IN
OUT
GND
1µF
100µF
A
N
E
T1
230V
15V
0V
15V
CON1
~
CT
~
D1
D2
D3
D4
A
K
REG1 LM317T
IN
OUT
ADJ
100nF
2200µF 25V
100nF
10µF
100Ω
VR1 2k
1k*
100µF
D5
D6
LED1
λ
CON2
+Vo
0V
–Vo
E
10µF
VR2 2k
1k*
100µF
D8
100nF
2200µF 25V
100nF
ADJ
IN
OUT
100Ω
D7
3.0k 0.5W
REG2 LM337T
* LINK OUT OR CHANGE THESE RESISTORS TO ALLOW A WIDER RANGE OF OUTPUT VOLTAGES
D1–D8: 1N4004
A
K
LED
K
A
MCP1700
IN
OUT
GND
7805
IN
GND
OUT
GND
LM317T
ADJ
OUT
IN
OUT
LM337T
ADJ
IN
OUT
IN
UNIVERSAL REGULATOR Mk2
VERSION A: CENTRE TAPPED TRANSFORMER SECONDARY, ADJUSTABLE DUAL OUTPUTS PLUS TWO FIXED POSITIVE REGULATORS

into the added resistors. This means you can't really reduce the dissipation per regulator by more than we did or you risk burning out the resistors.

Running from a DC supply

If you are using a regulated DC supply or battery, the considerations are much simpler. Around 3V headroom is required. So, for example, with a 12V DC supply the highest available output voltage will be 9V.

For a battery, calculate using the lowest expected terminal voltage. The current drawn from the DC supply is simply the sum of the current drawn from each regulator output, plus the quiescent current of around 25mA.

As mentioned earlier, you can't use the negative output if the regulator board is running off DC.

Circuit description

The full circuit is shown in Fig.1 and this is version A. Here we're assuming that the power supply is a mains transformer with a 30V centre-tapped secondary, or two 15V secondaries connected in series. These secondaries connect to a bridge rectifier formed by diodes D1-D4 on the board via terminal block CON1, to charge up two 2200µF electrolytic capacitors to roughly ±20V.

REG1 then regulates the +20V to somewhere between +13.2V and +17V, depending on the setting of VR1. Similarly, REG2 regulates the –20V rail to between –13.2V and –17V depending on how VR2 is set.

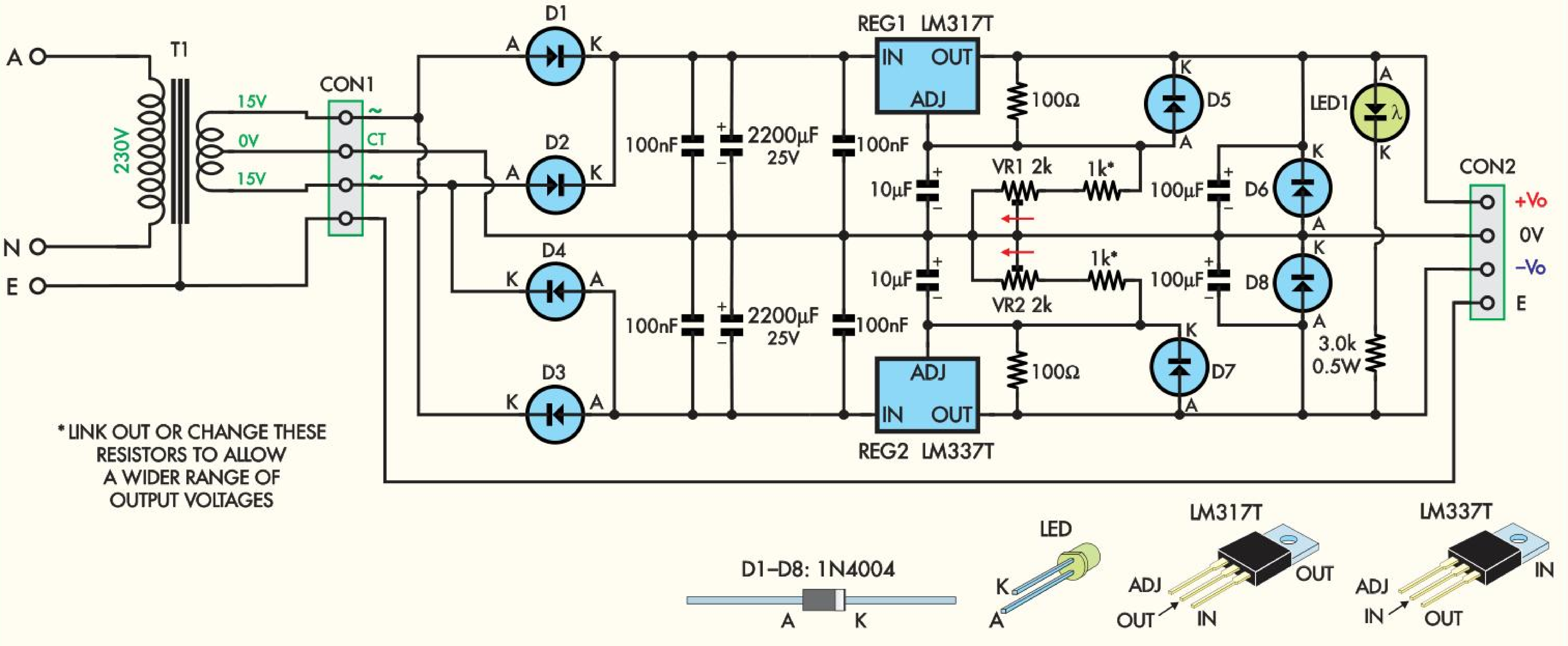
The lower limits of these voltages are determined by the ratio of the 1kΩ and 100Ω divider resistors, while the upper limits are determine by the need to have at least 2V of headroom for the regulators, when taking into account the ~1V ripple expected on the input capacitors with moderate (~100mA) loads on the regulators. Thus, if you need a lower output voltage you can reduce the 1kΩ values or link these resistors out entirely.

Similarly, you could change the 2kΩ trimpots to lower values (eg, 500Ω) to give a narrower adjustment range. This would make accurately setting the output voltage easier but would require the initial range (determined by those fixed resistors) to be set fairly accurately. When choosing fixed resistor values, factor half of the resistance of VR1/VR2 into the equation, so that these pots will be roughly centred at the required output voltage.

The formula to select these resistors is: **Vout ÷ 0.0125 – 100Ω**. Subtract half the trimpot resistance then pick the closest resistor value.

The 10µF capacitors from each ADJ terminal to ground greatly improve the ripple rejection for REG1 and REG2. That's because they reduce the impedance between the ADJ terminal and GND, which would otherwise be limited by the value of the resistors used in the divider. There are also 100µF capacitors at each regulator output to improve transient response.

Diodes D6 and D8 prevent the regulator outputs from being pulled negative at switch-on/switch-off by a load connected directly between +Vo and –Vo. This is an especially common problem when a transformer with a single secondary is being used, as depending on which part of the mains cycle power is applied, either the positive or negative rail will come up first and any capacitors across the output (typically within the load) will cause



UNIVERSAL REGULATOR Mk2 VERSION B: CENTRE TAPPED TRANSFORMER SECONDARY, ADJUSTABLE DUAL OUTPUTS

Fig.2: Version B is similar to Version A but omits the two fixed voltage regulators. This is the version to build if you only require split supply rails that can be set anywhere from +13.2V to +17V and –13.2V to –17V. Trimpot VR1 adjusts the positive rail, while VR2 adjusts the negative rail.

the other output to be pulled in the wrong direction.

LED1 is connected across both outputs and will light as long as there is more than a few volts between them.

REG3 provides the +5V rail and this runs from the output of REG1. There is quite a large voltage drop from the input filter capacitor (in this case, around 20V) and the 5V output, so this arrangement splits the dissipation between REG1 and REG3, both of which would normally be fitted with a heatsink. It also means the 5V rail will be very quiet and virtually free of 50/100Hz ripple. Input bypassing is provided by REG1's output capacitor, while a 100µF electrolytic capacitor provides output filtering.

REG4 derives the 3.3V rail from the 5V output and has 1µF ceramic capacitors at both input and output. REG4 can only handle an input voltage of up to 6V, thus REG3 is required if it is to be used. It can provide up to 250mA output and will only dissipate (5V – 3.3V) × 0.25A = 425mW at full load, well within the capabilities of the small TO-92 package (625mW).

Both the 3.3V and 5V rails are available at CON3, while the two main outputs and mains earth are at CON2. Note that you could change REG3 to a higher-voltage type of regulator if required, but then you would have to leave REG4 out as it will not handle the higher input voltage.

Note also that a mains earth connection is made between CON1 and CON2 but is not joined to the rest of the circuit. This would normally be connected to ground at the load end. In the *Balanced Attenuator* project, this allows for an Earth Lift switch to disconnect the two should the circuit be earthed elsewhere.

Other versions

Fig.2 shows version B of the circuit in which REG3 and REG4 are not fitted and the associated components have also been deleted. This is how you would build the board if you only need the two main (±) outputs, ie, without 5V or 3.3V rails.

Fig.3 shows version C, which is the same as version B but with two changes: (1) Trimpots VR1 and VR2 have been omitted. This reduces the cost slightly and gives fixed output voltages within about ±5% of the selected values (due to regulator and resistor tolerances). However, note that you may not be able to select resistors of exactly the value required to set your desired output voltage, thus the difference could be more than 5%.
(2) A 17VAC plugpack has been used and this does not have a centre-tapped secondary. As such, diodes D2 and D4 have been omitted since they are not used and D1 and D3 operate as two half-wave rectifiers. The disadvantage is that the filter capacitors are only recharged alternately at 50Hz rather than simultaneously at 100Hz – there is little choice here because few AC plugpacks have centre-tap connections available.

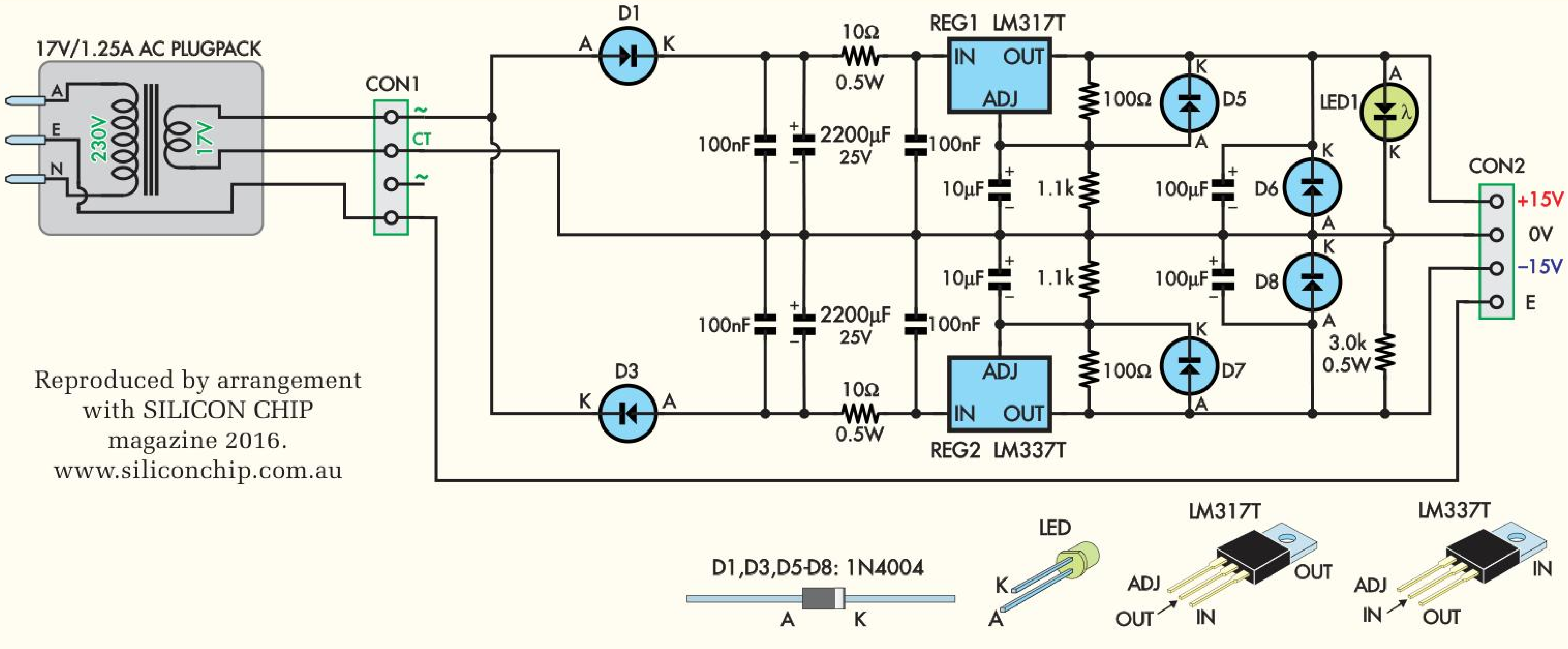
As explained earlier, this is the version used to power the *Balanced Input Attenuator* presented elsewhere in this issue.

The circuit in Fig.4 is similar to Fig.1, but all the components associated with the negative output have been removed. This is shown powered from a transformer with a centre-tapped secondary but a DC supply could also be used, with its negative output connected to the CT terminal of CON1 and its positive output to either of the remaining terminals (ignoring the earth connection, which could be left unconnected).

Note that the current-limiting resistor value for LED1 has been reduced as it is now running from a lower voltage without the presence of the negative rail.

Construction

Once you have decided which version to build, calculate the required resistor values to set the output voltage ranges. If you are fitting the optional voltage-dropping resistors you will need to calculate their value too, otherwise you will be fitting wire links in their place. Refer to the overlay diagram appropriate to the configuration you are


17V/1.25A AC PLUGPACK
230V
17V
A
E
N
CON1
~
CT
~
D1
A
K
D3
K
A
10Ω
0.5W
100nF
2200μF
25V
100nF
REG1 LM317T
IN
OUT
ADJ
ADJ
IN
OUT
REG2 LM337T
10μF
1.1k
100Ω
D5
100μF
D6
D7
D8
LED1
3.0k
0.5W
CON2
+15V
0V
–15V
E
D1,D3,D5-D8: 1N4004
LED
LM317T
LM337T
OUT
IN
K
A

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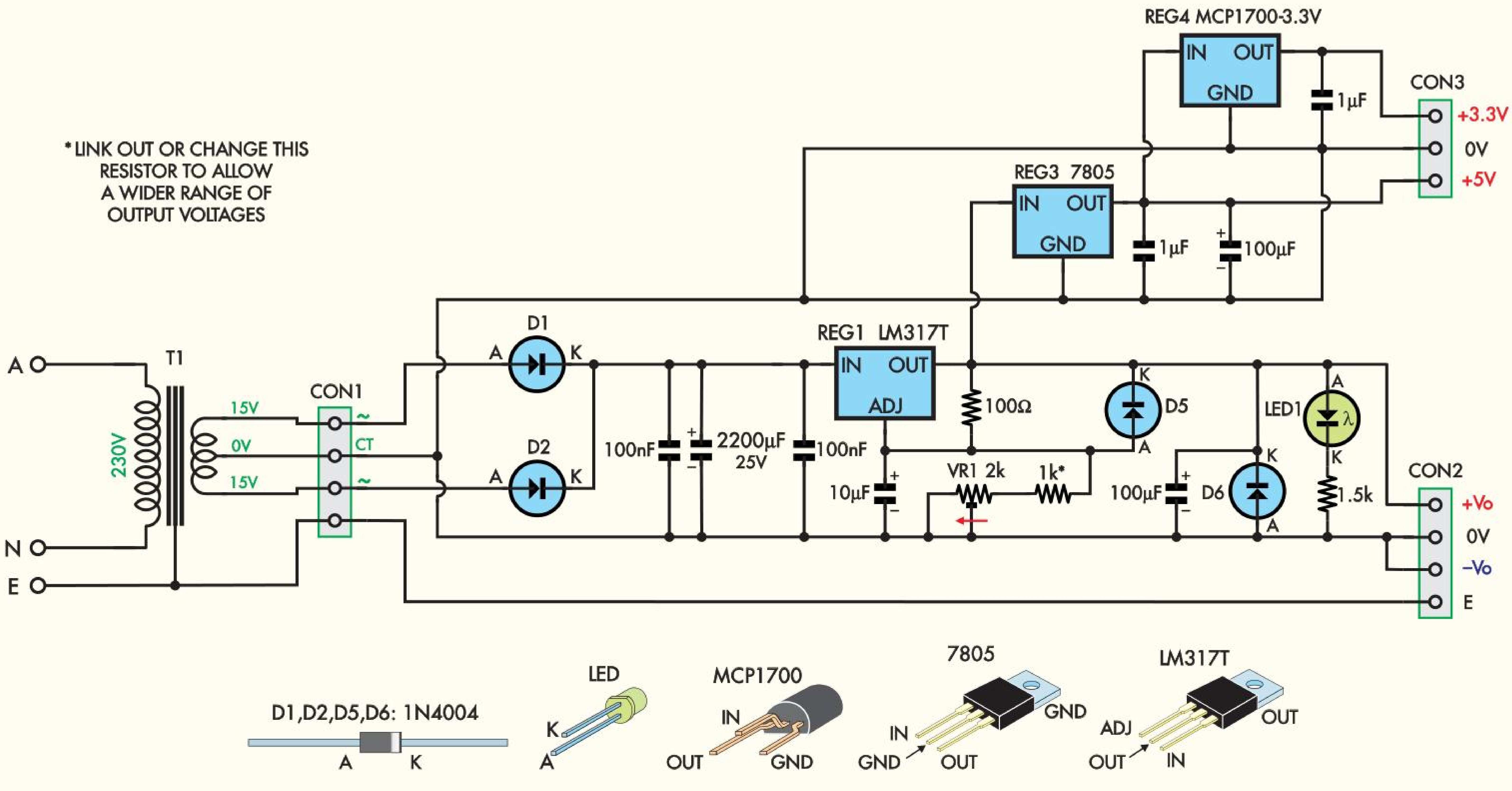
UNIVERSAL REGULATOR Mk2 VERSION C: UNTAPPED TRANSFORMER SECONDARY, DUAL ±15V OUTPUTS

Fig.3: Version C uses a 17VAC plugpack (ie, no centre-tap), with D1 and D3 operating as half-wave rectifiers. In addition, trimpots VR1 and VR2 have been omitted and the output rails set to ±15V by the 100Ω and 1.1kΩ resistors. This is the version that's used to power the *Balanced Input Attenuator* described elsewhere in this issue.


REG4 MCP1700-3.3V
IN
OUT
GND
1μF
CON3
+3.3V
0V
+5V
*LINK OUT OR CHANGE THIS RESISTOR TO ALLOW A WIDER RANGE OF OUTPUT VOLTAGES
REG3 7805
1μF
100μF
A
N
E
T1
230V
15V
0V
15V
CON1
~
CT
~
D1
D2
A
K
100nF
2200μF
25V
100nF
REG1 LM317T
ADJ
100Ω
10μF
VR1 2k
1k*
100μF
D5
D6
LED1
1.5k
CON2
+Vo
0V
–Vo
E
D1,D2,D5,D6: 1N4004
LED
MCP1700
7805
LM317T

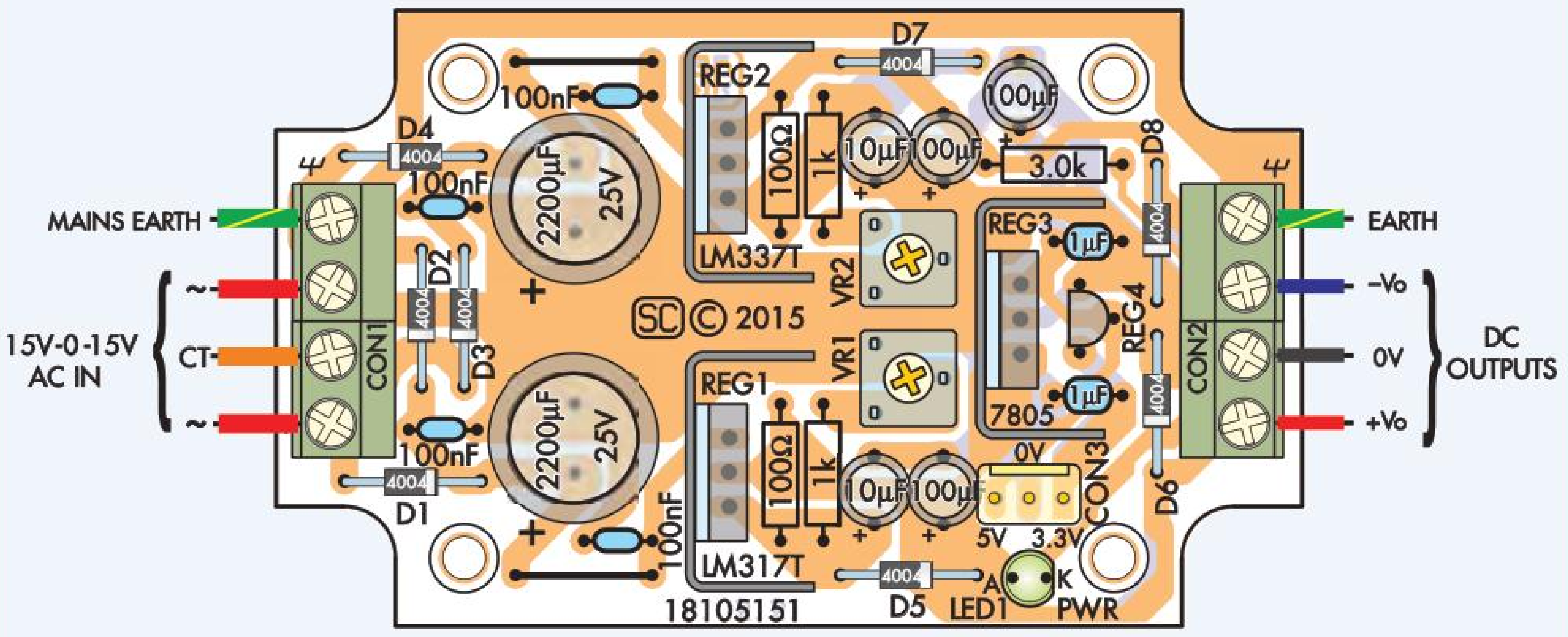
UNIVERSAL REGULATOR Mk2 VERSION D: CENTRE TAPPED TRANSFORMER SECONDARY, ADJUSTABLE POSITIVE OUTPUT PLUS TWO FIXED POSITIVE REGULATORS

Fig.4: Version D has fixed +3.3V and +5V outputs based on REG4 and REG3, plus a single +13.2V to +17V adjustable output based on REG1. It's similar to Version A but does away with the parts associated with the adjustable negative output rail. Note: linking out or changing the 1kΩ resistor allows a wider range of output voltages to be set (all versions).

building, which will be one of Figs.5-8 (or a variation thereof).

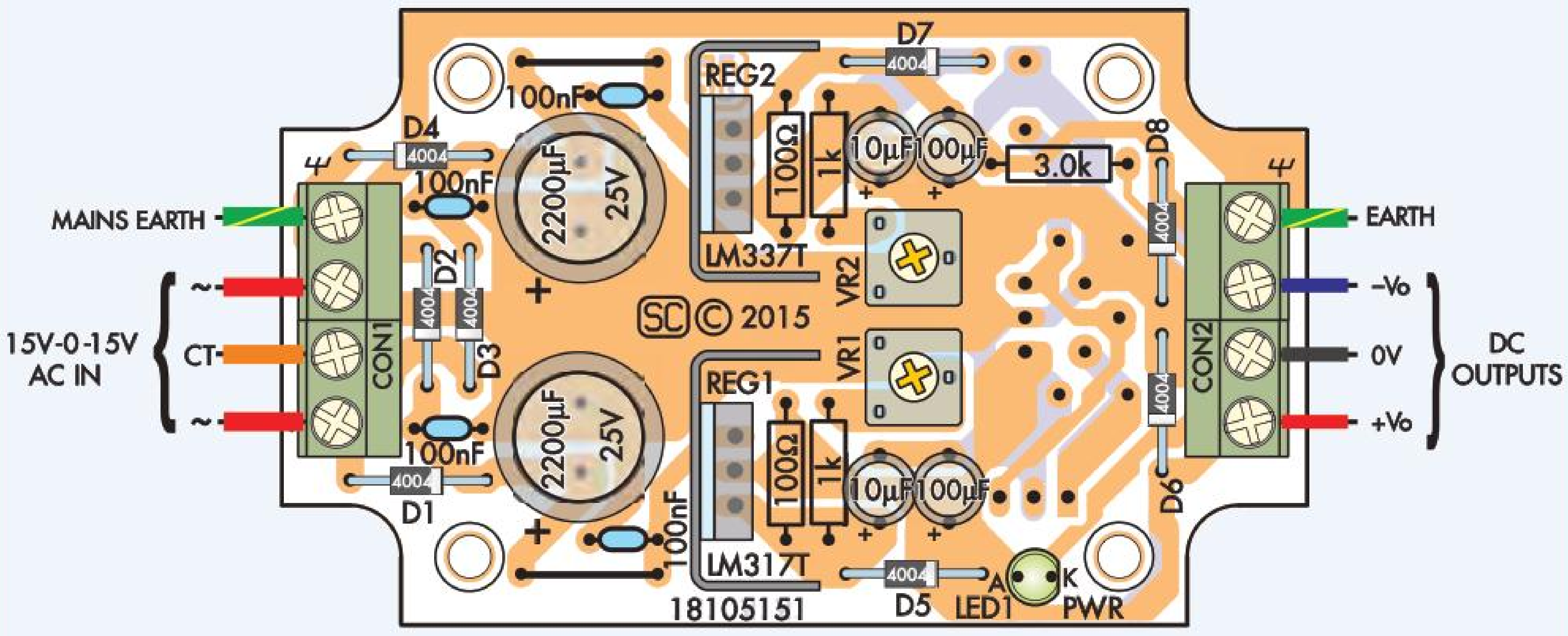
Start by fitting the resistors, keeping in mind any variations in value. If your version requires any wire links, form these from the resistor lead offcuts and solder them in place. Follow with the 1N4004 diodes, being careful to match up the orientation of each with the appropriate overlay diagram before soldering. There are between four and eight diodes depending on the version.

Fit the ceramic capacitors next, followed by trimpots VR1 and VR2. If you don't need to be able to adjust the


D7
4004
100nF
100µF
REG2
D4
100Ω
1k
10µF
100µF
3.0k
D8
MAINS EARTH
100nF
2200µF
25V
LM337T
REG3
1µF
EARTH
~
D2
VR2
–Vo
15V-0-15V
AC IN
CT
CON1
D3
SC © 2015
REG4
CON2
0V
DC
OUTPUTS
~
VR1
1µF
+Vo
REG1
7805
100nF
2200µF
25V
100Ω
1k
0V
D1
10µF
100µF
CON3
D6
100nF
5V
3.3V
LM317T
4004
A
K
18105151
D5
LED1
PWR

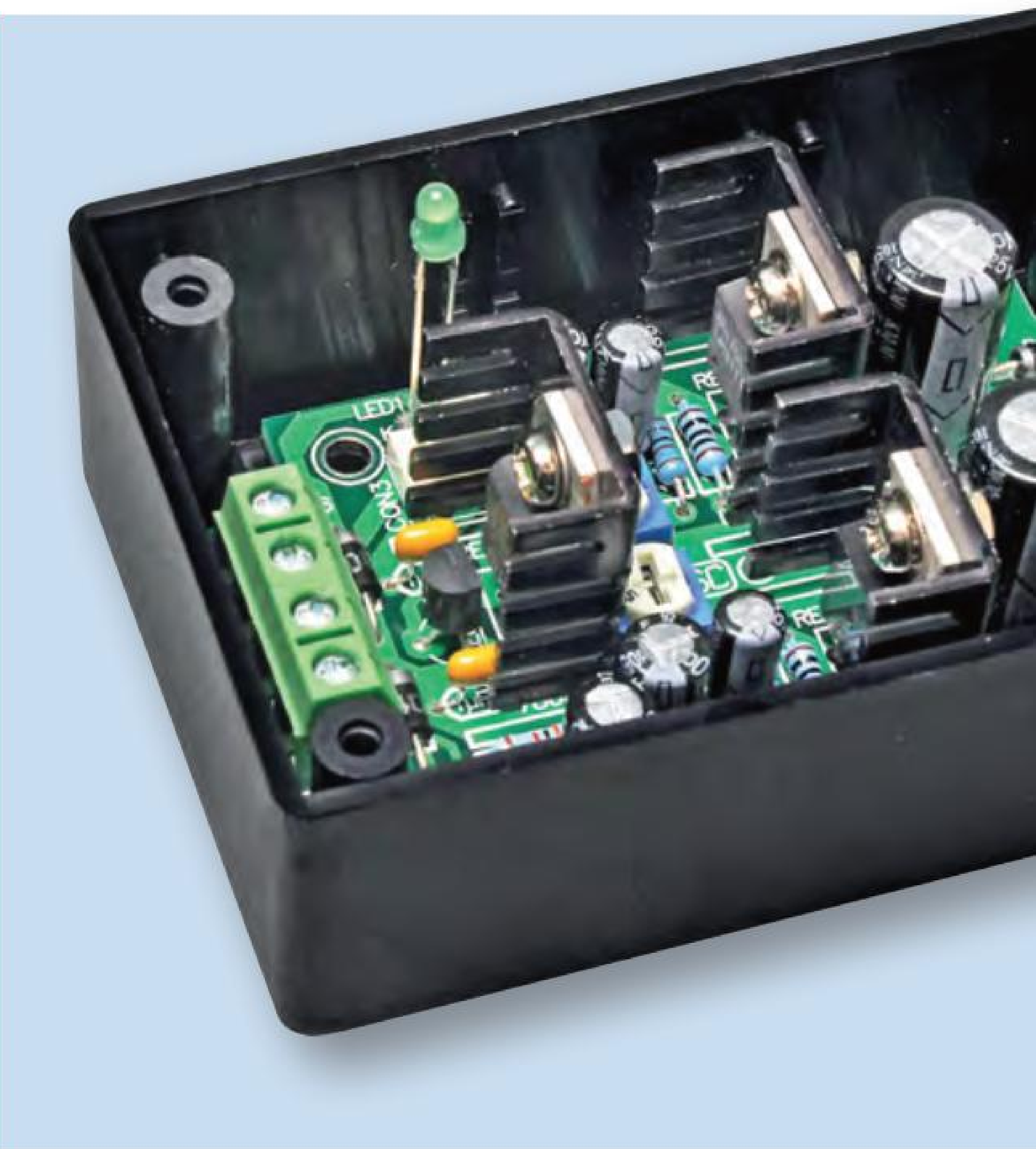
VERSION A: CENTRE TAPPED TRANSFORMER SECONDARY, ADJUSTABLE DUAL OUTPUTS PLUS TWO FIXED POSITIVE REGULATORS

Fig.5: this Version A board layout corresponds to the circuit diagram of Fig.1. All parts are installed on the PCB, with the adjustable outputs available at CON2 and the fixed +3.3V and +5V outputs at CON3.


D7
4004
100nF
REG2
D4
100Ω
1k
10µF
100µF
3.0k
D8
MAINS EARTH
100nF
2200µF
25V
LM337T
EARTH
~
D2
VR2
–Vo
15V-0-15V
AC IN
CT
CON1
D3
SC © 2015
CON2
0V
DC
OUTPUTS
~
VR1
+Vo
REG1
100nF
2200µF
25V
100Ω
1k
D1
10µF
100µF
D6
100nF
LM317T
4004
A
K
18105151
D5
LED1
PWR

VERSION B: CENTRE TAPPED TRANSFORMER SECONDARY, ADJUSTABLE DUAL OUTPUTS

Fig.6: follow this PCB layout to build Version B if you only require adjustable split rail outputs (ie, 13.2V to +17V and –13.2V to –17V). Note the heatsinks fitted to the regulators.



outputs and have selected appropriate resistors to give the required voltages, link them out as shown in Fig.7.

Next, dovetail the pairs of 2-way terminal blocks to form two 4-way blocks and place them on the PCB with the wire entry holes facing the nearest edge of the board. Ensure they are pushed down flat before soldering the pins. REG4 can then go in, if you are fitting it. If so, crank its leads out (eg, using small pliers) to suit the holes in the PCB.

CON3 can be fitted next, assuming you are using either of the auxiliary outputs.

The smaller electrolytic capacitors go in now. Be careful with their orientation; in each case, the longer positive lead goes towards the bottom of the board, as shown in Figs.5-8. You will probably need to crank the leads out to fit the PCB pads and depending on the size of the 100µF capacitors, you may find you need to bend them sideways a little in order to avoid interfering with adjacent components (see photos).

Now secure each TO-220 regulator you are using firmly to a small flag heatsink using an M3 × 6mm machine screw, shakeproof washer and nut. Make sure that each regulator is fitted straight on the heatsink, then drop it into place on the PCB. Check that its leads are inserted evenly and then solder and trim them. Repeat for any other regulators being installed.

The larger electrolytics can now go in, then all that's left is the power indicator LED. We arranged for ours to poke out through the lid of the jiffy box. To do this, solder it with the bottom of the lens 26mm from the top of the PCB. This is close to full lead length (about 5mm short). Ensure the longer anode lead goes into the hole to the left of the board, ie, with the orientation shown in Figs.5-8.

Testing and setting up

There isn't much to check. Connect your power supply temporarily to CON1 and power it on. Verify that LED1 lights, then measure the output voltages

Table 2: Capacitor Codes

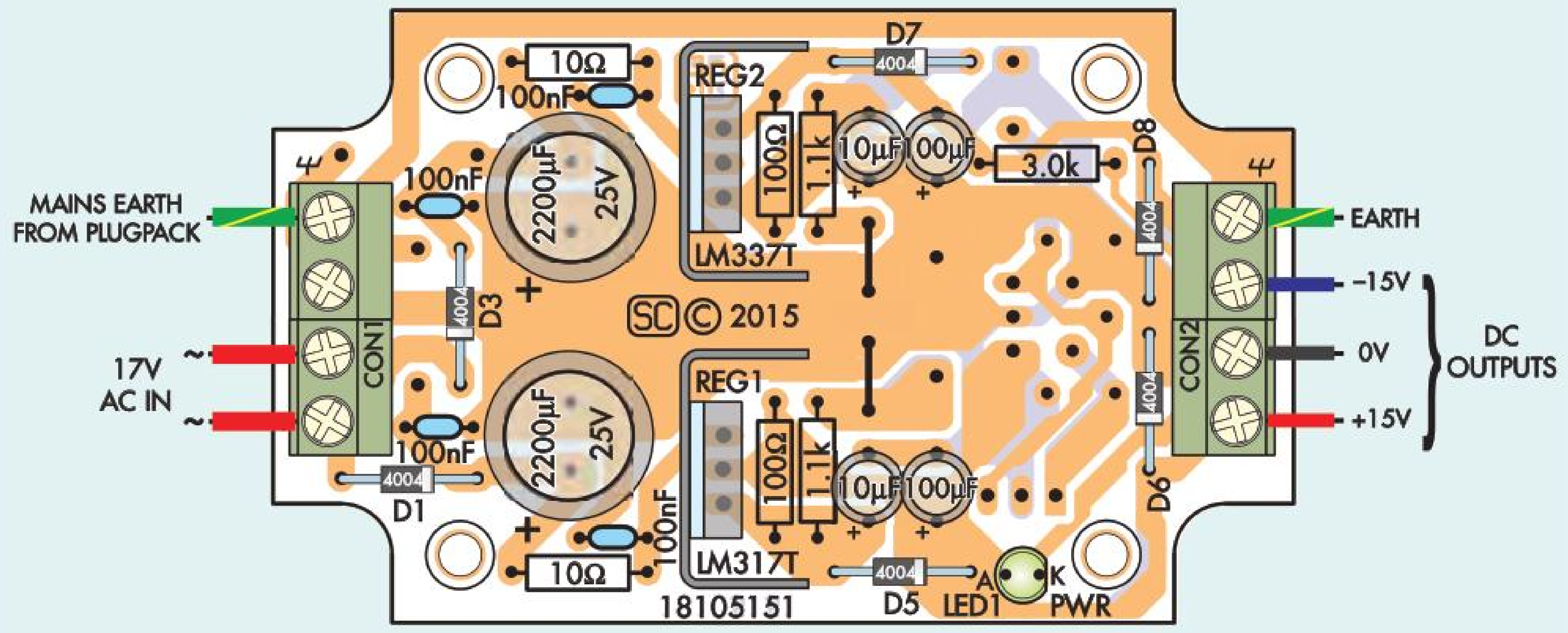
Value	µF Value	IEC Code	EIA Code
1µF	1µF	1u0	105
100nF	0.1µF	100n	104

Table 1: Resistor Colour Codes

☐	No.	Value	4-Band Code (1%)	5-Band Code (1%)
☐	1	3kΩ	orange black red brown	orange black black brown brown
☐	1	1.5kΩ	brown green red brown	brown green black brown brown
☐	2	1kΩ	brown black red brown	brown black black brown brown
☐	2	100Ω	brown black brown brown	brown black black black brown
☐	2	10Ω	brown black black brown	brown black black gold brown

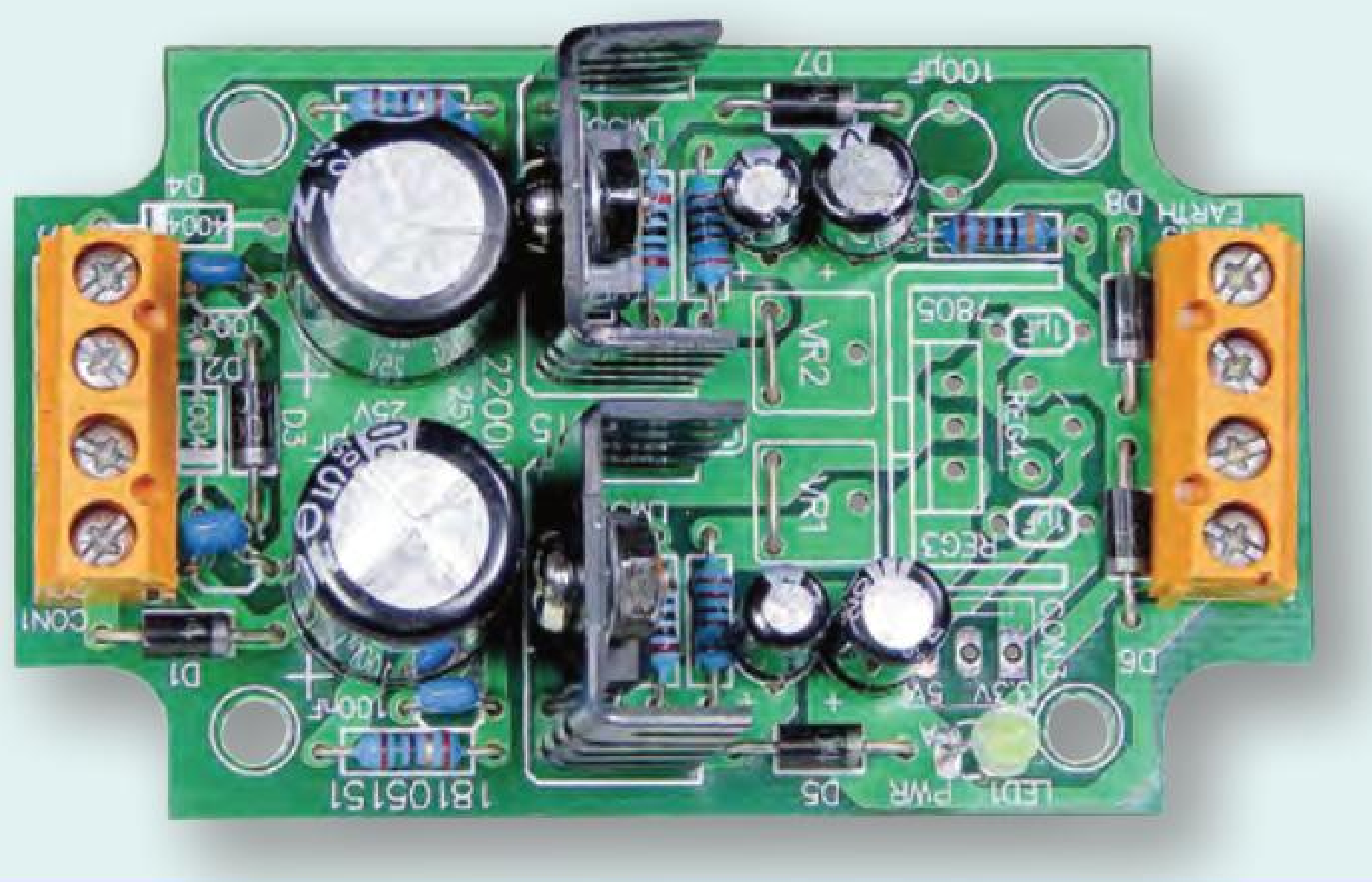
This photo shows the Version A board fitted into a UB5 plastic case. The power LED pokes through a hole in the lid.

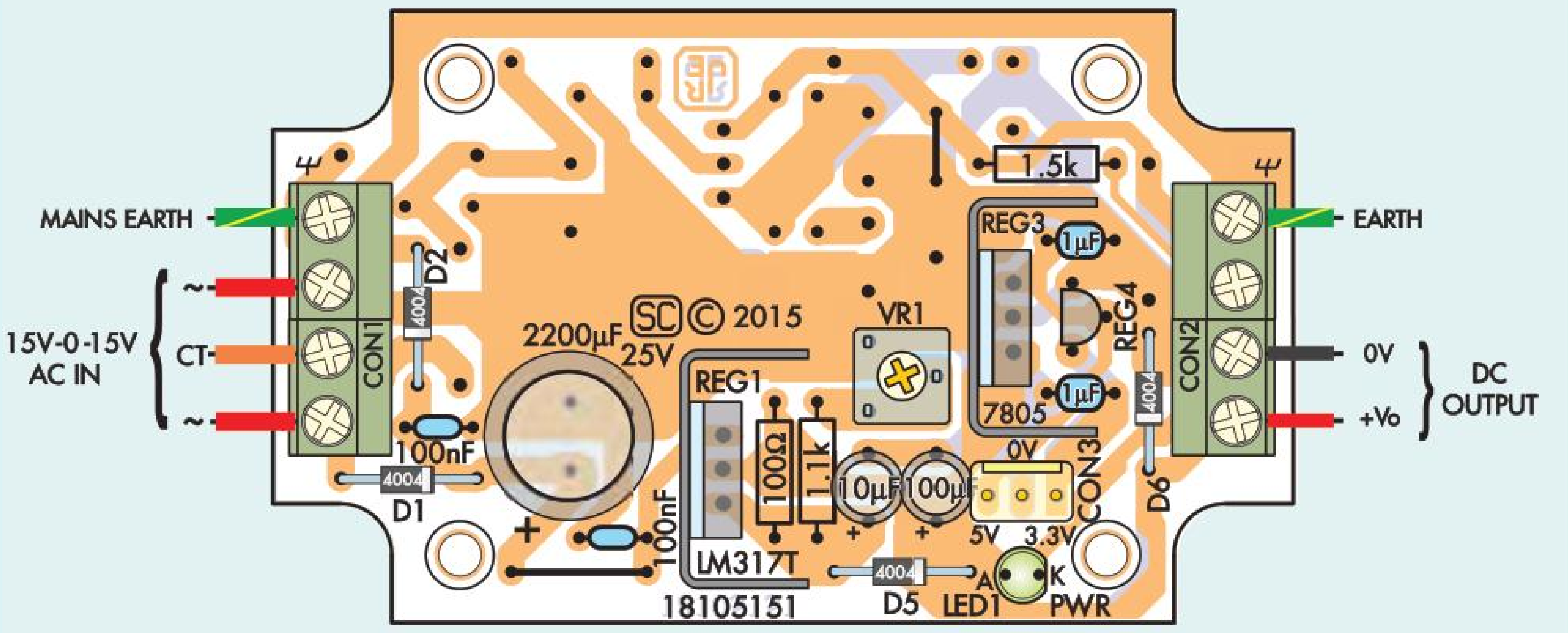
The completed unit can be attached to the back of a plugpack supply as shown here. It's shown taped into position here but could also be secured using silicone adhesive.


MAINS EARTH FROM PLUGPACK
17V AC IN
~
~
CON1
10Ω
100nF
100nF
2200µF 25V
D3
D1
4004
REG2
LM337T
100Ω
1.1k
10µF
100µF
D7
3.0k
D8
REG1
LM317T
SC © 2015
18105151
D5
LED1
A
K
PWR
D6
CON2
EARTH
−15V
0V
+15V
DC OUTPUTS

VERSION C: UNTAPPED TRANSFORMER SECONDARY, DUAL 15V OUTPUTS

Fig.7: the Version C PCB layout has fixed ±15V DC outputs and runs from a 17VAC plugpack (see parts list for *Balanced Attenuator*). This is the version to build to power the *Balanced Input Attenuator*. Below is the assembled PCB.




MAINS EARTH
15V-0-15V AC IN
~
CT
~
CON1
D2
4004
D1
2200µF 25V
100nF
SC © 2015
REG1
LM317T
100Ω
1.1k
10µF
100µF
VR1
1.5k
REG3
1µF
7805
REG4
CON3
0V
5V
3.3V
18105151
D5
LED1
A
K
PWR
D6
CON2
EARTH
0V
+Vo
DC OUTPUT

VERSION D: CENTRE TAPPED TRANSFORMER SECONDARY, ADJUSTABLE POSITIVE OUTPUT PLUS TWO FIXED POSITIVE REGULATORS

Fig.8: here's how to install the parts to build Version D. It has fixed +3.3V and +5V outputs at CON3, plus an adjustable +13.2V to +17V output at CON2.

and ensure they are correct. If VR1 and/or VR2 are fitted, simply adjust them to get the required voltage(s). If you can't, you may need to change the associated fixed resistors.

Putting it in a box

If you want to mount the board in a UB5 jiffy box as we did (and as we recommend for the *Balanced Input Attenuator* power supply), you will need to make some minor modifications. You can't slide the board into the pre-cut notches since the components are too tall, so you need to cut new notches 4mm tall at the bottom of each of the eight ribs using side-cutters and then pliers to remove the remainder. The board will then snap into the bottom of the case, with some cajoling.

Next, drill a 3mm hole in the upper-left corner of the lid for the power LED. This goes 10mm from the long side and 23mm from the short side of the lid. Check the position with respect to the PCB before drilling it.

Two holes are required in the left-hand and righthand ends of the box for the input and output cables. Because the terminal blocks mount so close to the ends of the box, these will need to be made fairly high up and then the individual wires looped down to reach the board. You may wish to fit grommets in these holes, with the right diameter for the cable you've chosen to use for your regulator.

For the *Balanced Input Attenuator*, the input cable from the plugpack has three wires and these are connected as shown in Fig.7. The output goes to a 4-wire shielded cable fitted with a 5-pin DIN plug. The wiring details for this cable are shown in the *Balanced Input Attenuator* article.

Once the unit has been tested and the lid screwed onto the box, you can then use double-sided tape to attach it to the rear of the plugpack itself – see adjacent photo.

Teach-In 2016

Exploring the Arduino

Part 4: Measuring temperature

by Mike and Richard Tooley

AREF
GND
13
12
~11
~10
~9
8
7
~6
~5
4
~3
2
TX→1
RX←0
DIGITAL (PWM~)
L
TX
RX
SMD EDITION
UNO
ON
ARDUINO
ICSP
RESET EN
ARDUINO.CC
MADE IN ITALY
IOREF
RESET
3.3V
5V
GND
Vin
POWER
ANALOG IN
A0
A1
A2
A3
A4
A5

Welcome to *Teach-In 2016: Exploring the Arduino*. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. So, whether you are considering what to do with your Arduino, or maybe have an idea for a project but don't know how to turn it into reality, our new *Teach-In 2016* series will provide you with a one-stop source of ideas and practical information.

In last month's *Teach-In 2016 Exploring Arduino* we looked at interfacing displays and keypads that can be used with the Arduino. To this end, *Arduino Workshop* dealt with interfacing a low-cost LCD display while *Arduino World* looked at keypads and buttons. Our programming feature, *Coding Quickstart*, introduced characters arrays, strings and string manipulation and some of the functions that can help you manipulate characters and text. Finally, *Get Real* showed you how to use a low-cost matrix keyboard and LCD display together in a simple but highly effective entry/access control system based on the Arduino Uno.

This month

In this month's *Teach-In 2016: Exploring the Arduino* we will be looking at ways in which the Arduino can sense and act upon what's going on in the real world. To achieve this, *Arduino Workshop* looks at the Arduino's analogue ports, while *Arduino World* introduces some low-cost devices that can sense temperature. Our programming feature, *Coding Quickstart*, explains the functions that will let you use serial communication via the Arduino's USB port. Finally, *Get Real* shows you how you can build a simple thermostatic controller based on the Arduino Uno.

Arduino Workshop: Using the analogue ports

In many practical control applications there's a need to be able to deal with analogue as well as digital inputs. Fortunately, the Arduino Uno provides you with six analogue inputs that are adequate for most applications. To use one of the analogue inputs you first need to decide which pin is to be used for the input and indicate this in your code. For example, when using analogue input A0 you would do this by including a line at the start of your sketch of the form:

```
int analogInput = 0;    // Use analogue input A0
```

Next, you will need to assign a variable which will receive the raw data from the ADC when you read the state of the analogue pin in question. This will take the following form:

```
int value;              // Raw data from the ADC
```

Now, to actually read the voltage present on the input and store it as a 10-bit value in the range 0 to 1023 you could use:

```
value = analogRead(analogInput); // Read the input
```

The 10-bit integer value returned by the ADC will be on a scale determined by the ADC's reference voltage. This is usually +5V, but it may be set to other voltages if the need arises.

In some applications you may need to convert the 10-bit value from the ADC into a corresponding voltage. To do this, you will need to convert the value returned by the ADC and store it in a new variable, using a `float` variable type since you will no longer be dealing with an integer value. The scaling factor (assuming that you are using the default 5V reference voltage) will simply be 1024/5 = 204.8.

Resolution

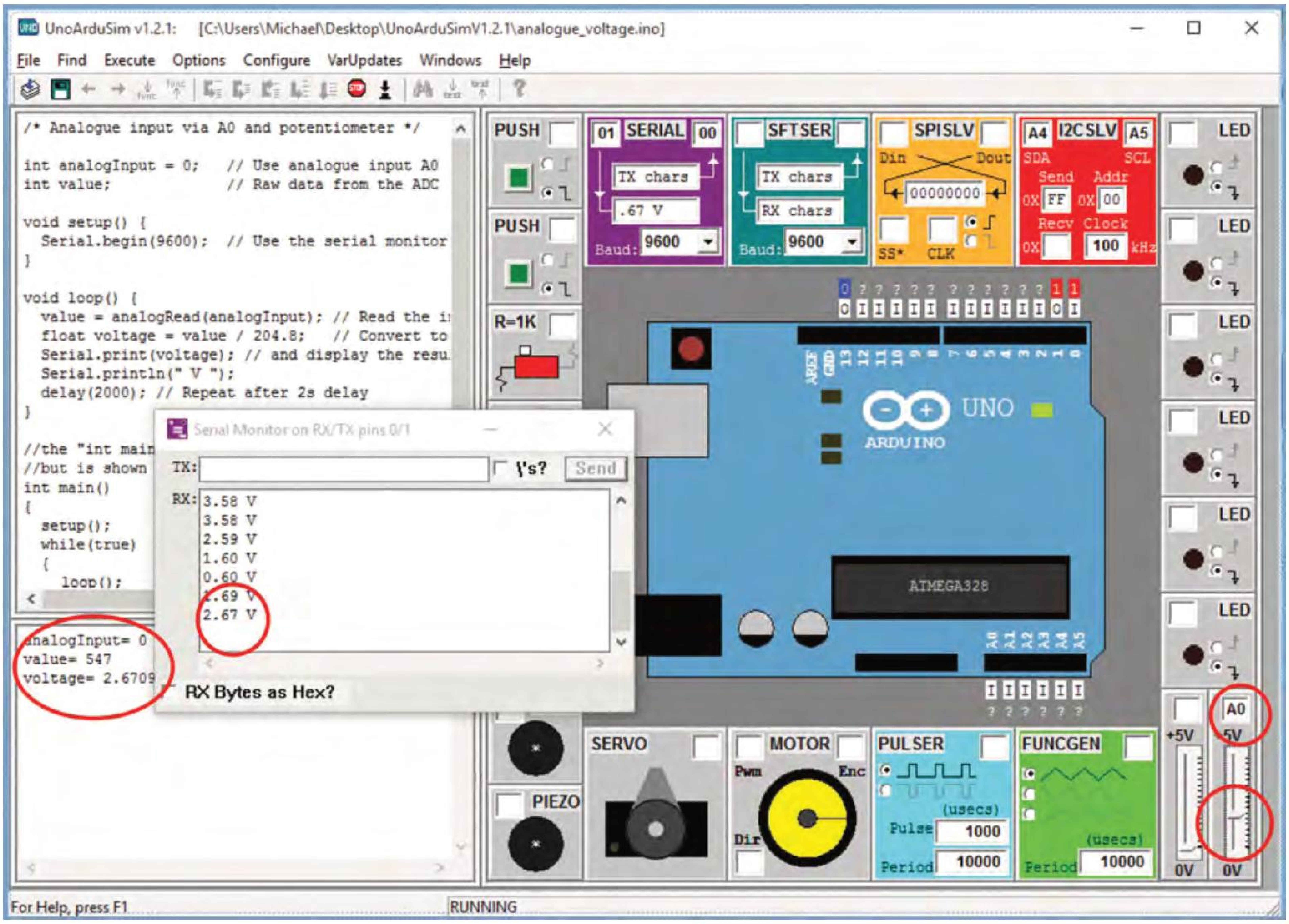
The step size of the ADC defines the converter's resolution. For a 5V reference and a 10-bit converter the step size will be 5V/1024 = 4.88mV. The maximum possible value that can be returned from a 10-bit value will have all ten bits set and its binary value will thus be 1111111111 corresponding to a value that is $2^{10} - 1$ or 1023. Multiplying the step size by this value gives the maximum indicated voltage, which will be 4.88mV × 1023 = 4.992V (not 5V which is often quoted erroneously). Resolution can be improved by reducing the ADC reference voltage input. Changing this from 5V to 2.5V would give a resolution of 2.44mV, but the maximum voltage that could be measured would then be marginally less than 2.5V.

Testing the analogue ports

To help make all this clear, Listing 4.1 shows a program that you can run in UnoArduSim. When you've entered and saved the code you will need to enter A0 in the text field above the potentiometer in the bottom right of the screen and start the Serial Monitor from the Windows menu (see Fig.4.1). If you now select Execute followed by Run you will be able to adjust the slider of the potentiometer and note the voltages displayed in the Serial Monitor, as shown in Fig.4.1. Of course, if you want to test the program for real you only need to connect a 10kΩ linear variable potentiometer to the Arduino and then enter and run Listing 4.1 from the Arduino's IDE. The wiring is shown in Fig.4.2.

Arduino World: Temperature sensors

Being able to sense and respond to changes in temperature is an important requirement in any environmental monitoring application. Fortunately, temperature sensing has never been easier using popular low-cost three-pin TO92 packaged temperature sensors like the TMP36 and


UnoArduSim v1.2.1: [C:\Users\Michael\Desktop\UnoArduSimV1.2.1\analogue_voltage.ino]
File
Find
Execute
Options
Configure
VarUpdates
Windows
Help
PUSH
R=1K
SERIAL
TX chars
.67 V
Baud: 9600
SFTSER
RX chars
SPISLV
Din
Dout
00000000
SS*
CLK
I2CSLV
SDA
SCL
Send
Addr
Recv
Clock
100 kHz
LED
UNO
ARDUINO
ATMEGA328
SERVO
PIEZO
MOTOR
Pwm
Enc
Dir
PULSER
Pulse 1000
Period 10000
FUNCGEN
Period 10000
A0
+5V
5V
0V
Serial Monitor on RX/TX pins 0/1
TX:
\'s?
Send
RX:
RX Bytes as Hex?
For Help, press F1
RUNNING

```
/* Analogue input via A0 and potentiometer */

int analogInput = 0;    // Use analogue input A0
int value;              // Raw data from the ADC

void setup() {
  Serial.begin(9600);  // Use the serial monitor
}

void loop() {
  value = analogRead(analogInput); // Read the i
  float voltage = value / 204.8;    // Convert to
  Serial.print(voltage); // and display the resu
  Serial.println(" V ");
  delay(2000); // Repeat after 2s delay
}

//the "int main
//but is shown
int main()
{
  setup();
  while(true)
  {
    loop();
```

```
3.58 V
3.58 V
2.59 V
1.60 V
0.60 V
.69 V
2.67 V
```

```
nalogInput= 0
value= 547
voltage= 2.6709
```

Fig.4.1. The operation of the Uno's analogue ports can be easily simulated using UnoArduSim

LM35. These two devices are very similar and they are both very easily interfaced to the Arduino's analogue inputs, as we will see later. They both provide an analogue output that varies on a linear basis at 10mV per degree Celsius. However, there's a notable difference in the temperature range covered and the scaling that needs to be applied when converting raw data from these two sensors to temperature output that can be displayed in °C. Using the regulated 3.3V supply from the Arduino, the TMP36 will read from –40° C to +125°C, while the LM35 will operate from +2°C to +150°C with reasonable accuracy.

When using either of these sensors, a useful tip is to use the Arduino's 3.3V supply rather than the 5V supply because this is more stable and noise free – but do note that a different scaling factor will be required if you are converting to voltage. In addition, when using remotely mounted sensors we recommend fitting 100nF capacitors between each analogue input and ground to improve noise reduction, which may be a problem in some environments, and also where stray RF signals might be present.

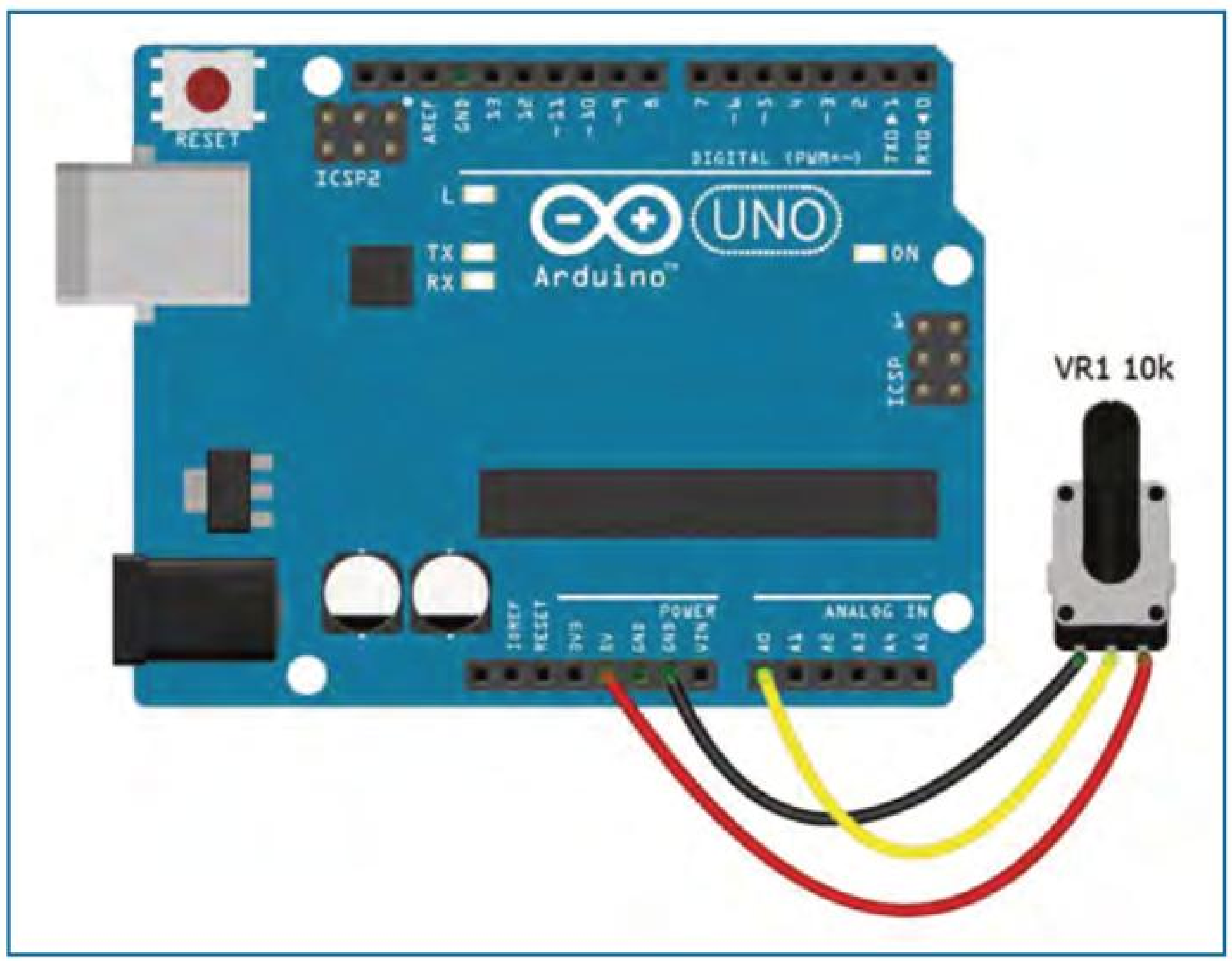

RESET
ICSP2
AREF
GND
DIGITAL (PWM~)
TX
RX
L
ON
UNO
Arduino
ICSP
POWER
ANALOG IN
VR1 10k

Fig.4.2. Fritzing schematic – the analogue port test code

Listing 4.1: Testing the Arduino Uno's analogue inputs

```
/* Analogue input via A0 and potentiometer */

int analogInput = 0;   // Use analogue input A0
int value;             // Raw data from the ADC

void setup() {
     Serial.begin(9600);  // Use the serial monitor
}

void loop() {
     value = analogRead(analogInput); // Read the input
     float voltage = value / 204.8;   // Convert to V
     Serial.print(voltage); // and display the result
     Serial.println(" V");
     delay(2000); // Repeat after 2s delay
}
```

Using the TMP35 family of temperature sensors

The TMP35, TMP36 and TMP37 sensors are members of a family of devices that together are capable of covering a temperature range from –40°C to +125°C with an accuracy better than ±2°C (and typically ±1°C at +25°C). Usefully, each of the sensors in the range produce an output voltage that is linearly proportional to the Celsius temperature, as illustrated in Fig.4.3. All three devices are available in low-cost three-lead TO-92, eight-lead SOIC, and five-lead SOT-23 surface-mount packages and they are thus ideal for building into miniature probes.

Table 4.1 TMP35 series temperature sensor specifications

Device	TMP35	TMP36	TMP37
Useful temperature range	+10°C to +125°C	−40°C to +125°C	+5°C to +100°C
Output voltage at 25°C	250mV	750mV	500mV
Temperature characteristic	10mV/°C	10mV/°C	20mV/°C

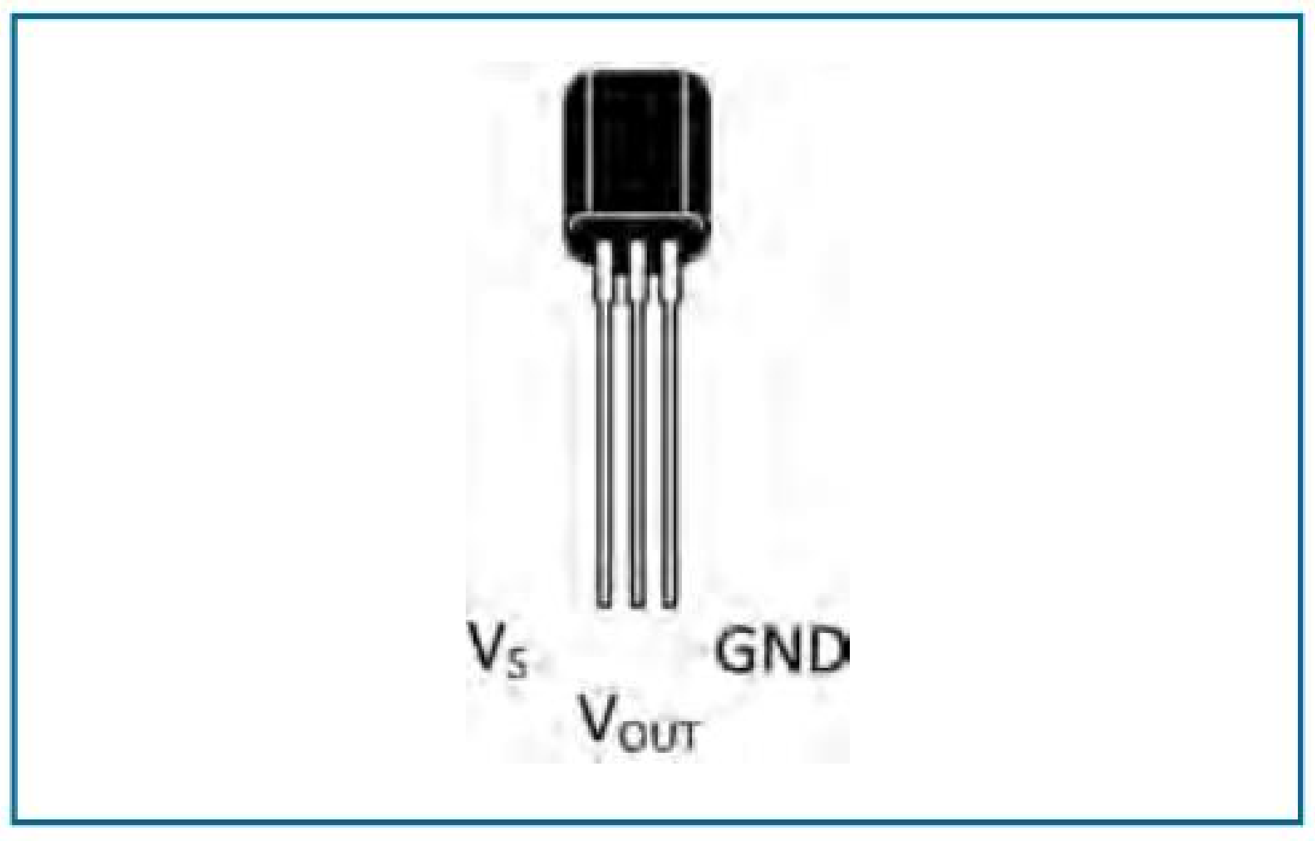


Fig.4.5. Pin connections for the TMP35, TMP36 and TMP37 temperature sensors

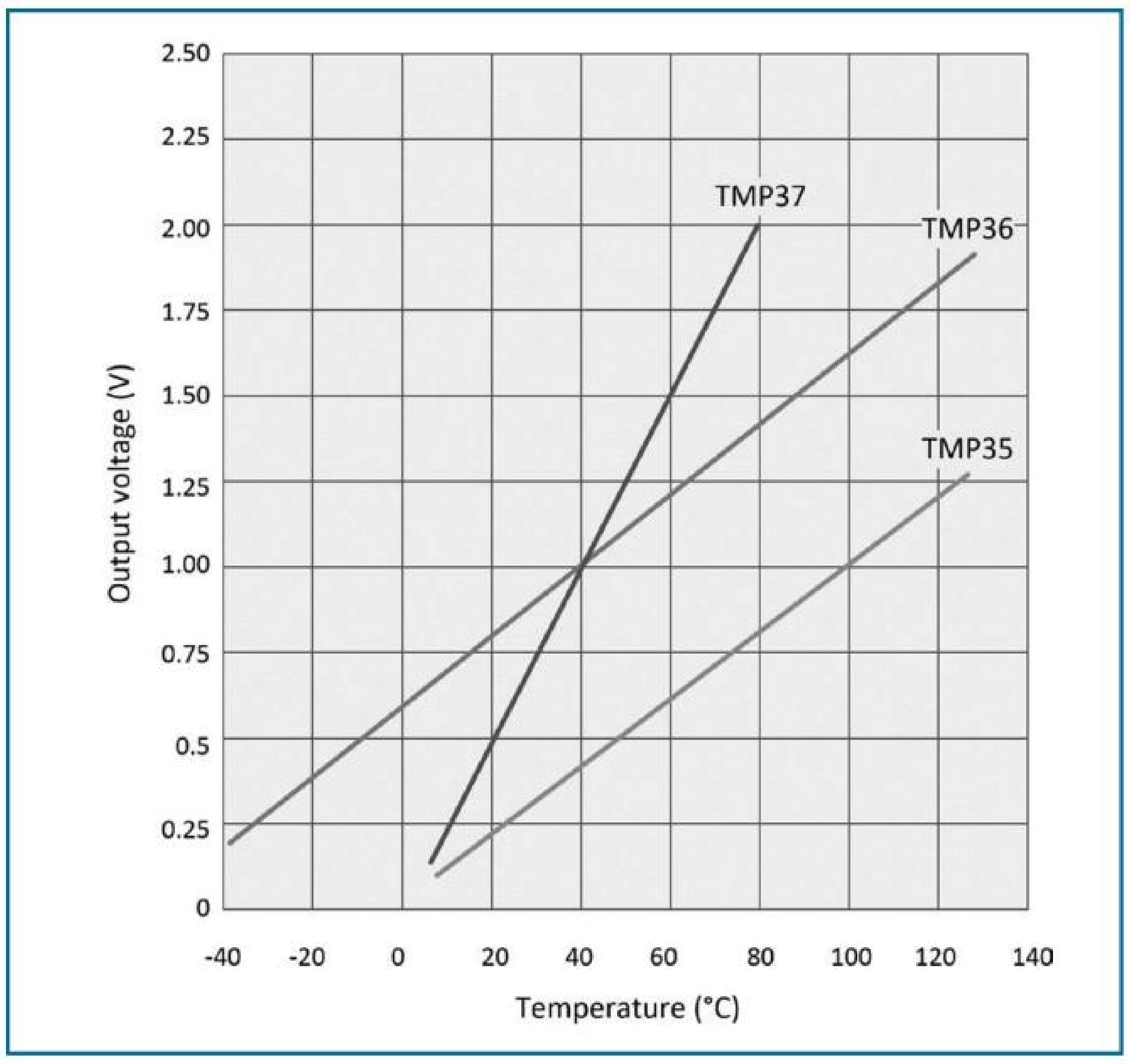


Fig.4.3. Characteristics of the TMP35, TMP36 and TMP37 temperature sensors

The TMP35 family of sensors is intended for single-supply operation from 2.7V to 5.5V (max) and they are thus eminently suitable for operation from the Arduino's +3.3V or +5V supplies. To avoid the risks associated with self-heating the chip requires only a very small supply current (well below 50μA). In addition, a shut-down function is provided that limits the residual supply current to less than 0.5μA.

The TMP35 provides an output of 250mV at 25°C and is suitable for sensing temperatures in the range +10°C to +125°C. The two other devices in the series are specified from −40°C to +125°C (TMP36) and +5°C to +100°C (TMP37). The TMP36 provides an output voltage of 750mV at +25°C, while the TMP37 produces 500mV at the same temperature (see Fig.4.3). To help you select the right sensor we've summarised their characteristics in Table 4.1. For most applications, and to indicate the widest range of temperatures, we recommend the TMP36 sensor.

Interfacing to the Arduino

The interface to the Uno's analogue port (see Fig.4.4) is extremely simple and only the temperature sensor is required. The pin connections for the TMP35, TMP36 and TMP37 temperature sensors are shown in Fig.4.5.

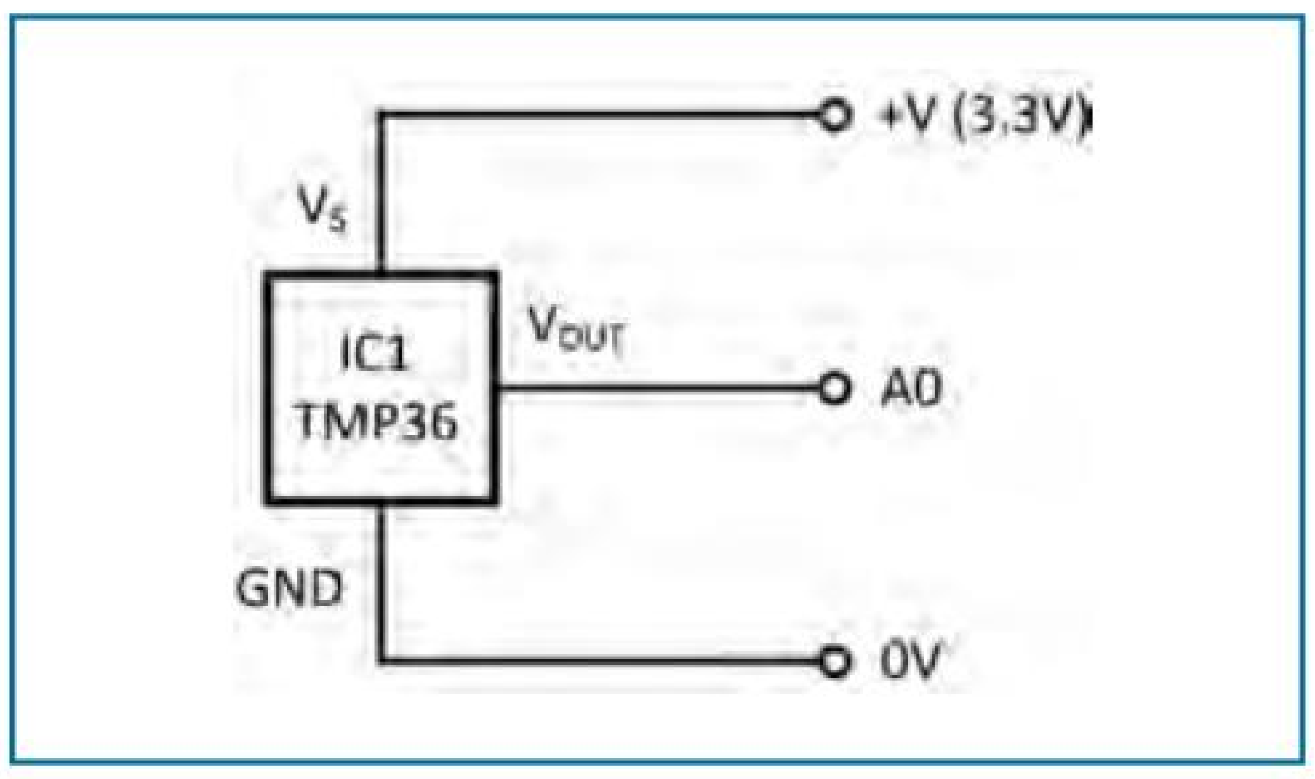


Fig.4.4. Temperature measurement interface

Using the LM35 series of temperature sensors

The LM35 series of precision integrated circuit temperature sensors provides another simple solution to temperature sensing with an Arduino. Like the TMP33 series, the output voltage from these sensors is linearly proportional to Celsius temperature. At normal room temperature, accuracies of around ±0.25˚C can be achieved. Over the full −55˚C to +150˚C range the accuracy is around ±1˚C. These devices can thus offer somewhat higher accuracy than those in the TMP35 series, but for many applications this is probably not a particularly important consideration. The LM35 series of chips use around 60μA from a 5V supply and exhibit very low self-heating (less than 0.1˚C in still air).

The LM35 is supplied in various packages, including a hermetic TO-46 package and a conventional plastic TO-92 transistor package. The LM35D is also available in an eight-lead surface mount small outline package and a plastic TO-220 package. It is worth noting that to sense temperatures below 0˚C with an LM35 device it is necessary to make use of a negative supply (as well as a positive supply). This makes this family of devices less attractive for use with an Arduino since it lacks a negative supply rail.

Interfacing to the Arduino is again very simple and follows the same arrangement that we showed earlier for the TMP35 series of chips (see Fig.4.4). The pin connections for the TO92 packaged version of the device are the same as those for the TMP35 (see Fig.4.5).

Coding

Due to the different characteristics of the TMP35 and LM35 series of sensors slightly different coding will be needed, as the following code fragments show:

TMP36 code

```
// TMP36 sensor conversion to deg.C
sensorValue = analogRead(TM36);
sensorVoltage = (sensorValue/1024.0)*5.0;
// 10mv per deg.C with offset of 500mV
sensorTemperature = (sensorVoltage - 0.5)*100;
```

LM35 code

```
// LM35 sensor conversion to deg.C
sensorValue = analogRead(LM35);
sensorVoltage = (sensorValue/1024.0)*5.0;
// 10mv per deg.C with no offset
sensorTemperature = sensorVoltage*100.0;
```

Notice that with the TMP36 we need to take into account the 500mV offset (see Fig.4.3).

A simple digital thermometer

To put this into context, Listing 4.2 shows how a TMP36 sensor can be used with an Arduino Uno and an LCD display (see last month's *Teach-In 2016*) to build a simple digital thermometer which will provide indications over a temperature range extending from −40°C to +125°C with an accuracy of around ±1˚C. The TMP36 is connected to analogue input A0 and the LCD is connected to digital I/O pins 2 to 7.

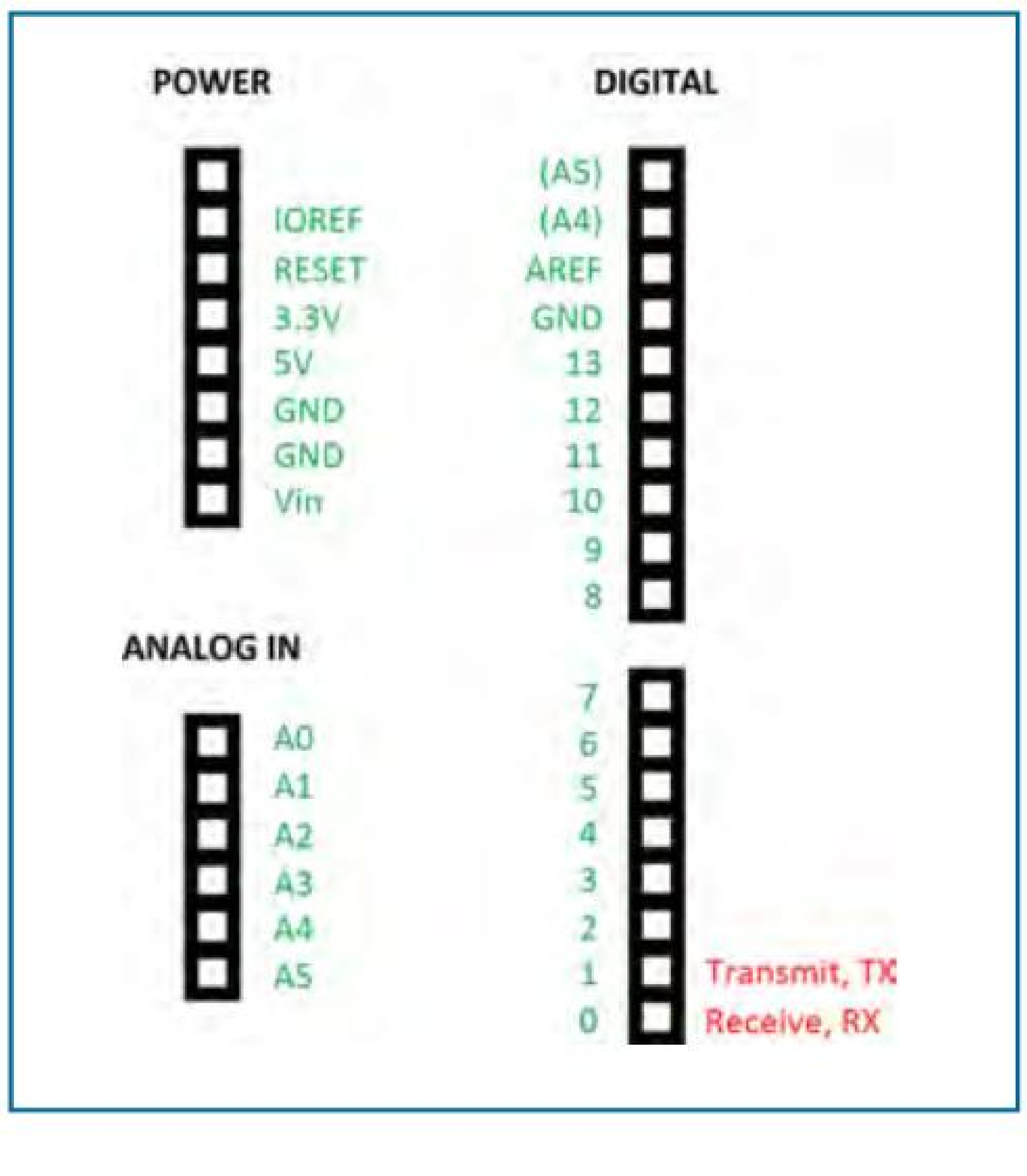


Fig.4.6. I/O connections for serial communication using the Uno's UART

Listing 4.2 A simple digital thermometer

```
/* Thermometer using TMP36 sensor */

#include <LiquidCrystal.h>    // Include the LCD library

LiquidCrystal lcd(7, 6, 5, 4, 3, 2);  // I/O pin numbers for the LCD

const int sensor = A0;  // TMP36 connected to analog input A05

void setup() {
  // set up the LCD's number of columns and rows:
  lcd.begin(16, 2);    // Display has 16 columns and 2 rows
  lcd.print("Temperature :");   // Display a message
  pinMode(sensor,INPUT); // A0 is an input
}

void loop() {
  lcd.setCursor(0, 1); // Begin on the second line
  float sensorVoltage, sensorTemperature;
  int sensorValue;
  // Get sensor value and convert to deg.C
  sensorValue = analogRead(sensor);
  // Convert value to voltage
  sensorVoltage = (sensorValue/1024.0)*5.0;
  // Convert voltage to temperature
  sensorTemperature = (sensorVoltage - 0.5) * 100 ;
  // Dislay the temperature
  lcd.setCursor(0, 1); // Use second line of the display
  // Print temperature of TMP36 sensor
  lcd.print(sensorTemperature);
  lcd.print(" ");
  lcd.write(B11011111); // upper 'o' symbol
  lcd.print("C");
  delay(1000); // Wait one second
}
```

Coding Quickstart : Serial communication via USB

As an aid to communication, the Arduino has a serial interface, which is sometimes referred to as a UART or USART (universal asynchronous receiver/transmitter and universal serial asynchronous receiver/transmitter). The UART interface uses digital I/O pins 0 and 1 (see Fig.4.6). Pin-0 is used for receive and is labeled 'RX', and pin-1 is used for transmit and is labeled 'TX'. It is important to be aware that the voltages on these pins are standard 5V TTL-compatible, so care must be taken with external devices (such as conventional RS-232 hardware) that use different voltage levels.

To communicate with an external TTL serial device you can simply connect the Arduino's TX pin to the RX pin on your device, while the RX pin on your Arduino is connected to the TX pin on your device. In addition, you will need to make a ground connection from your Arduino to the external device. Once again, it's essential to only use TTL-compatible hardware.

Arduinos (including the popular Uno and Nano variants) are also equipped with a standard USB port, which allows the board to be programmed by a computer. The USB port communicates using the *same* RX and TX signals, so you *must not* attempt to use pins 0 and 1 for communication if you are making use of the USB port. (You might have noticed that we've been avoiding the use of these two pins in our projects.)

Using the Serial Monitor

If you've followed the series this far you will already have made use of the Arduino's Serial Monitor. This handy gadget provides you with a simple but effective way of sending messages from the Arduino that you can display on a host computer. The host computer can also send short messages back to the Arduino. However, before you can begin to use serial communications you need to initialize the Serial Monitor within the `setup()` code like this:

```
void setup() {
Serial.begin(9600);
}
```

You've probably noticed the parameter that we've used in the `Serial.begin()` function. This sets the speed or data rate in bits per second (baud) that will be used for serial communication. It can be set to any of the following: 300, 600, 1200, 2400, 4800, 9600, 14400, 19200, 28800, 38400, 57600, or 115200. An optional second argument configures the data, parity, and stop bits. The default is eight data bits, no parity and one stop bit. This should work fine with the Arduino IDE and many other applications, but you may need to change it for some types of external hardware. For example, the following code sets the serial UART to 4800 bits per second with eight data bits, even parity and two stop bits:

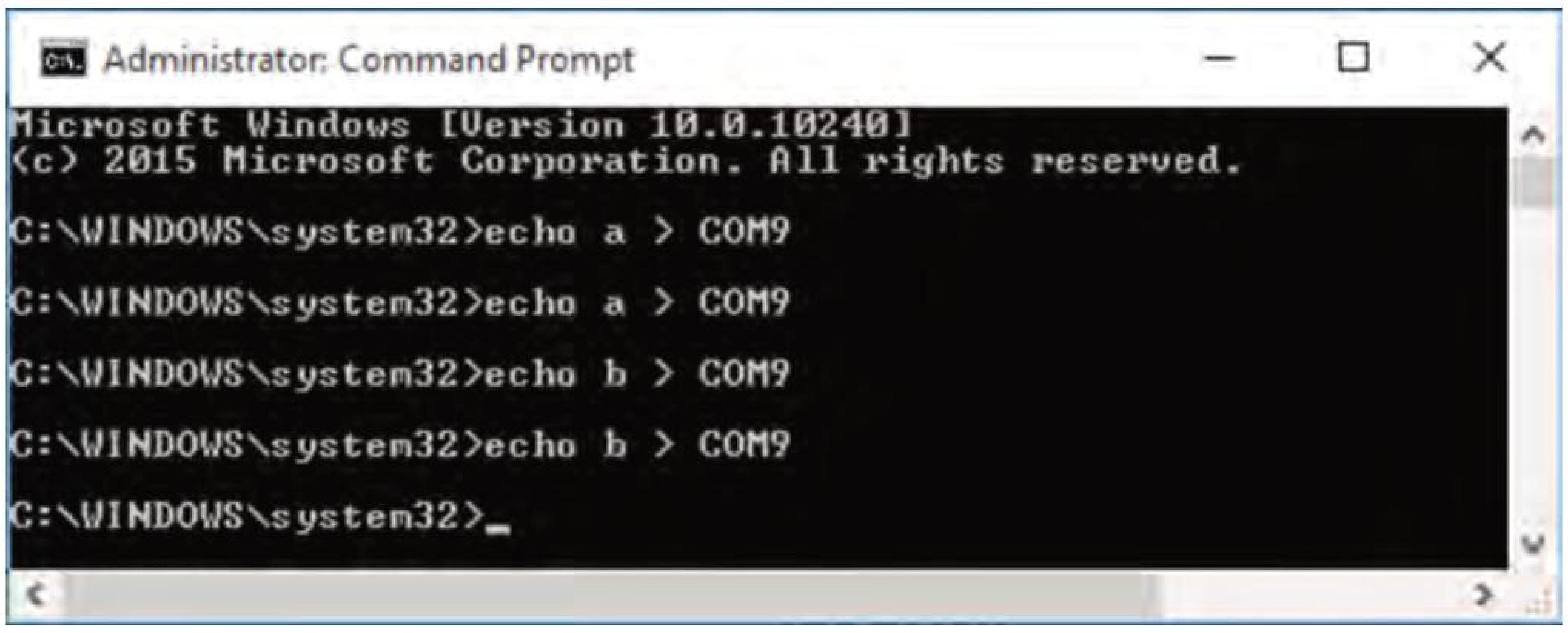
```
void setup() {
Serial.begin(9600, SERIAL_8E2); // Initialize the Serial Monitor
}
```

To send a message to the Serial Monitor you can use the `Serial.print` and `Serial.println()` functions. The only difference between these functions is that the latter adds a newline character at the end of the printed string. Here's an example:

```
Serial.print("Pin selected = ");
```

This will print the enclosed in the quotes and the next item to be printed will appear *immediately after* the trailing space. So, if we wanted to add a pin number stored in the variable `selectedPin` and then move to the *next* line we would use:

```
Serial.println(selectedPin);
```



```
Microsoft Windows [Version 10.0.10240]
(c) 2015 Microsoft Corporation. All rights reserved.

C:\WINDOWS\system32>echo a > COM9

C:\WINDOWS\system32>echo a > COM9

C:\WINDOWS\system32>echo b > COM9

C:\WINDOWS\system32>echo b > COM9

C:\WINDOWS\system32>_
```

Fig.4.7. Using the command line interface for serial communication with an Arduino Uno running the code in Listing 4.4. Shown here, using COM port 9 to send commands to the Uno

Listing 4.3 is an example that shows how characters can be sent to an Arduino, assembled into a string and then sent back to be printed using the Arduino's Serial Monitor. You will need to ensure that the 'Newline' option is selected from the Serial Monitor.

Listing 4.4 is another example of how you can use the serial interface. In this example we are going to use the serial interface to control two relays from a PC. The relays are assigned keyboard values 'A' and 'B', but we've allowed for the fact that the keys could be shifted (to upper case) or entered as lower-case values.

Finally, it's not always necessary to make use of the Arduino's IDE for serial communication. You can use a serial port monitor or even use the command line interface, as shown in Fig.4.7.

Get Real : a thermostatic controller

In this month's *Get Real* we describe a useful project that has a wide range of applications in the home and at work. This takes the form of a thermostatic controller that provides outputs for both heating and cooling. The controller's upper and lower threshold temperatures can be set in software to within 1°C and the temperature is displayed using a low-cost backlit 16 × 2 LCD. These are available cheaply from several suppliers.

A typical application for the thermostatic controller is control of a greenhouse or conservatory, in which case the low-temperature threshold would be set at around 4°C to prevent freezing. At the other extreme, the upper temperature threshold would be set at around 26°C in order to open a roof vent and/or operate a ceiling fan. Some experimentation might be necessary to arrive at the right temperature settings for a particular application.

You will need:

Arduino Uno with power supply
USB Type-A to Type-B cable
Computer with an available powered USB port
1 TMP36 semiconductor temp sensor
1 16 × 2 LCD 1602-type display
1 Arduino Uno prototype shield (see text)
1 low-cost relay two-channel board (with suitably rated contacts)
1 10kΩ miniature skeleton pre-set potentiometer, RV1
1 330Ω 0.25W resistor, R1
2 100nF miniature ceramic capacitors, C1 and C2
1 SPST switch, S1
1 9V battery (see text), B1
1 small piece of stripboard
Connecting wires and PCB headers (see text)

Listing 4.3 Assembling a serial string

```
/* Assemble a serial string from input characters.
Ensure that 'Newline' is enabled in the Serial Monitor
so that the returned string can be printed */

String inputString = "";         // a string to hold incoming data
boolean stringComplete = false;  // whether the string is complete

void setup() {
  Serial.begin(9600);
  inputString.reserve(64);  // 64 bytes reserved for the input
}

void loop() {
    if (stringComplete) {
    Serial.println(inputString); // Print the string
    inputString = ""; // and get ready for the next
    stringComplete = false;
  }
}

void serialEvent() {
  while (Serial.available()) {
    char inChar = (char)Serial.read(); // get a character
    inputString += inChar;  // and add it to the string
    // Check to see if the character was a new line
    // in which case the string is complete
    if (inChar == '\n') {
      stringComplete = true;
    }
  }
}
```

Listing 4.4 Sending commands using single keys (A and B) in either upper or lower case

```
/* PC to Arduino Uno using the serial USB interface
Upload and then open the Serial Monitor to send a
single keyboard character to toggle A and B relays */

const int relayA = 2; // Relay A is connected to digital pin-2
const int relayB = 3; // Relay B is connected to digital pin-3
boolean StatusA = LOW;
boolean StatusB = LOW;

void setup() {
  Serial.begin(9600); // Use Serial Monitor to send commands
  pinMode(relayA, OUTPUT);
  pinMode(relayB, OUTPUT);
  // Start with both loads turned off
  digitalWrite(relayA, HIGH);
  digitalWrite(relayB, HIGH);
}

void loop() {
   char ch = Serial.read(); // Check for a character
   if ((ch == 'A')||(ch == 'a'))
   {
      digitalWrite(relayA, StatusA);
      StatusA = !StatusA;
   }
   if ((ch == 'B')||(ch == 'b'))
   {
      digitalWrite(relayB, StatusB);
      StatusB = !StatusB;
   }
}
```

Circuit

The complete circuit of our Arduino Uno thermostatic controller is shown in Fig.4.8. The circuit uses low-cost commonly available components. The two-channel relay board and 16 × 2 LCD display are widely available from a number of suppliers, including those based in the Far East.

The relays should be adequately rated for the loads that you wish to control. Those used in the prototype were rated

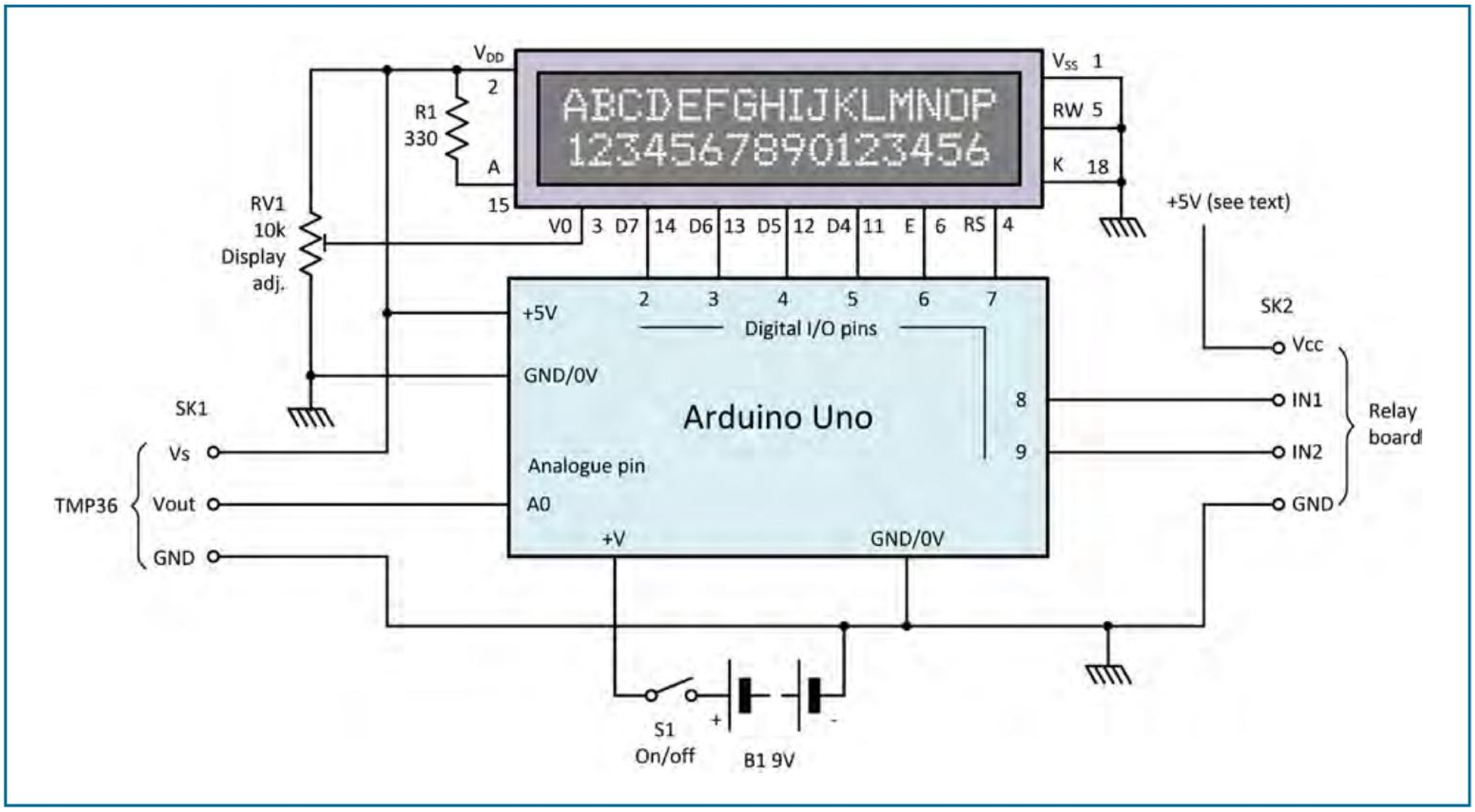

V$_{DD}$
2
R1
330
A
15
ABCDEFGHIJKLMNOP
1234567890123456
V$_{SS}$ 1
RW 5
K 18
+5V (see text)
RV1
10k
Display
adj.
V0 3 D7 14 D6 13 D5 12 D4 11 E 6 RS 4
+5V
2 3 4 5 6 7
Digital I/O pins
GND/0V
Arduino Uno
8
9
Analogue pin
A0
+V
GND/0V
SK1
Vs
TMP36
Vout
GND
SK2
Vcc
IN1
IN2
GND
Relay board
S1
On/off
B1 9V
+
-

Fig.4.8. Complete circuit of the Arduino-Uno-based thermostatic controller

at 10A 250V AC, which is adequate for most domestic applications. A four-way header, SK1, provides connection to the relay board, and six-way headers are used for the LCD display.

The prototype shield mounts directly over the Arduino Uno and provides a convenient and low-cost way of assembling the components and making connections to the Uno's I/O and power headers. The temperature sensor can be mounted on a small piece of stripboard and connected to the Arduino with a three-way header (see Fig.4.10). If necessary, the probe can be encapsulated and hermetically sealed for use in a moist environment, such as a greenhouse.

Code

Listing 4.5 shows the complete code for the simple Arduino-based thermostatic controller. Once again, to help you understand what's going on we've included numerous comments in the code. The code requires three libraries; `LiquidCrystal.h`, and `math.h`. The first of these provides functions that facilitate the use of the LCD display; the second deals with rounding the temperature values before they are sent to the display.

As with our previous *Get Real* projects, the code should first be entered into the IDE and then saved before compiling and uploading it to the Uno – as described in last month's *Arduino Workshop*. When you have debugged and corrected your code, don't forget to save it by clicking on 'File' and 'Save' or 'Save As…'. Next click on 'Sketch' and 'Verify/Compile'. Any compilation errors will then be reported in the window at the bottom of the IDE. Don't forget that if they are not already present, you may need to add library files using the IDE's File Manager. The procedure for adding and managing

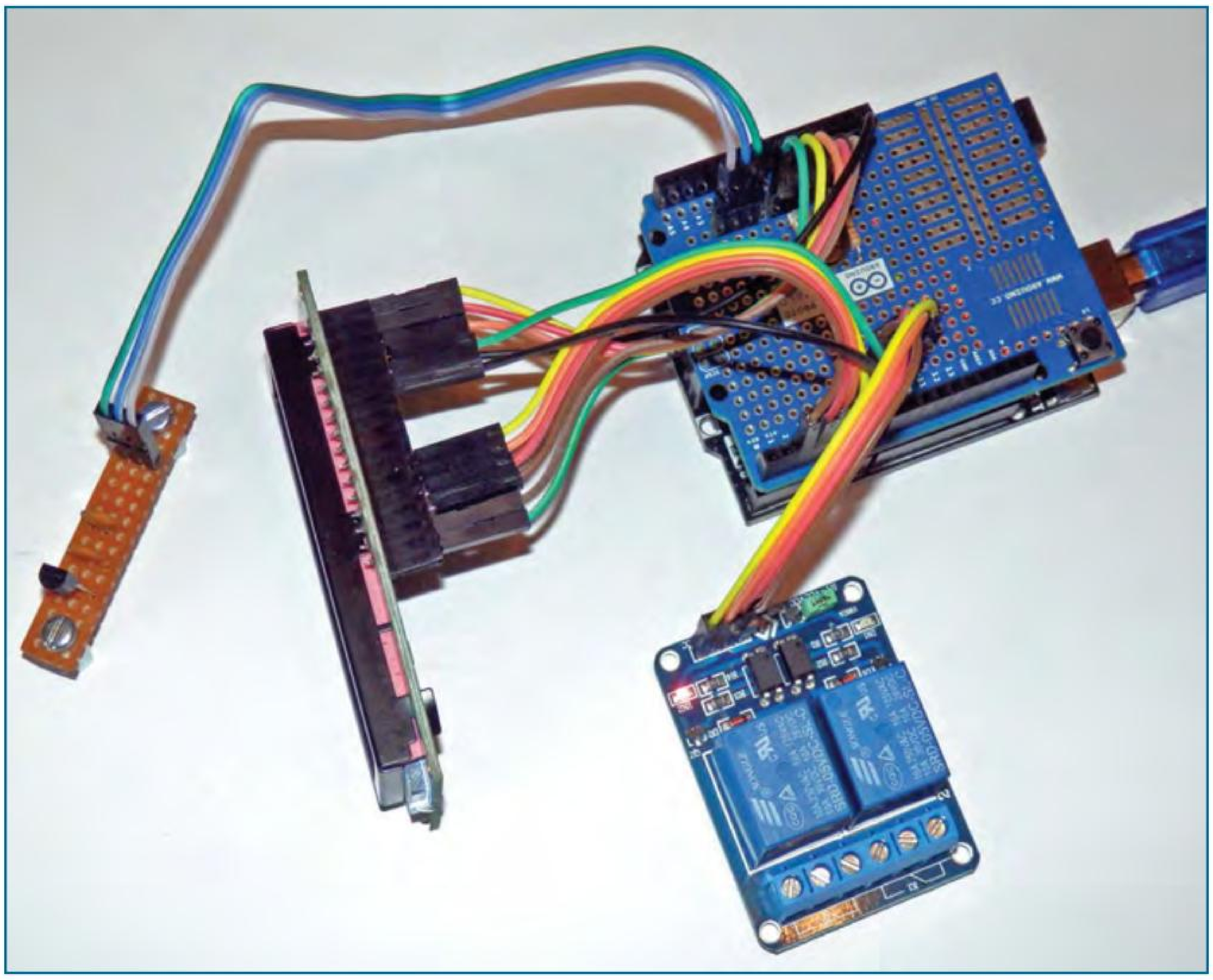


Fig.4.9. The complete Arduino Uno thermostatic controller showing the temperature sensor and backlit 16 × 2 LCD on the left and the two-channel relay board at the bottom. The blue lead at the right is the USB programming connection to the PC

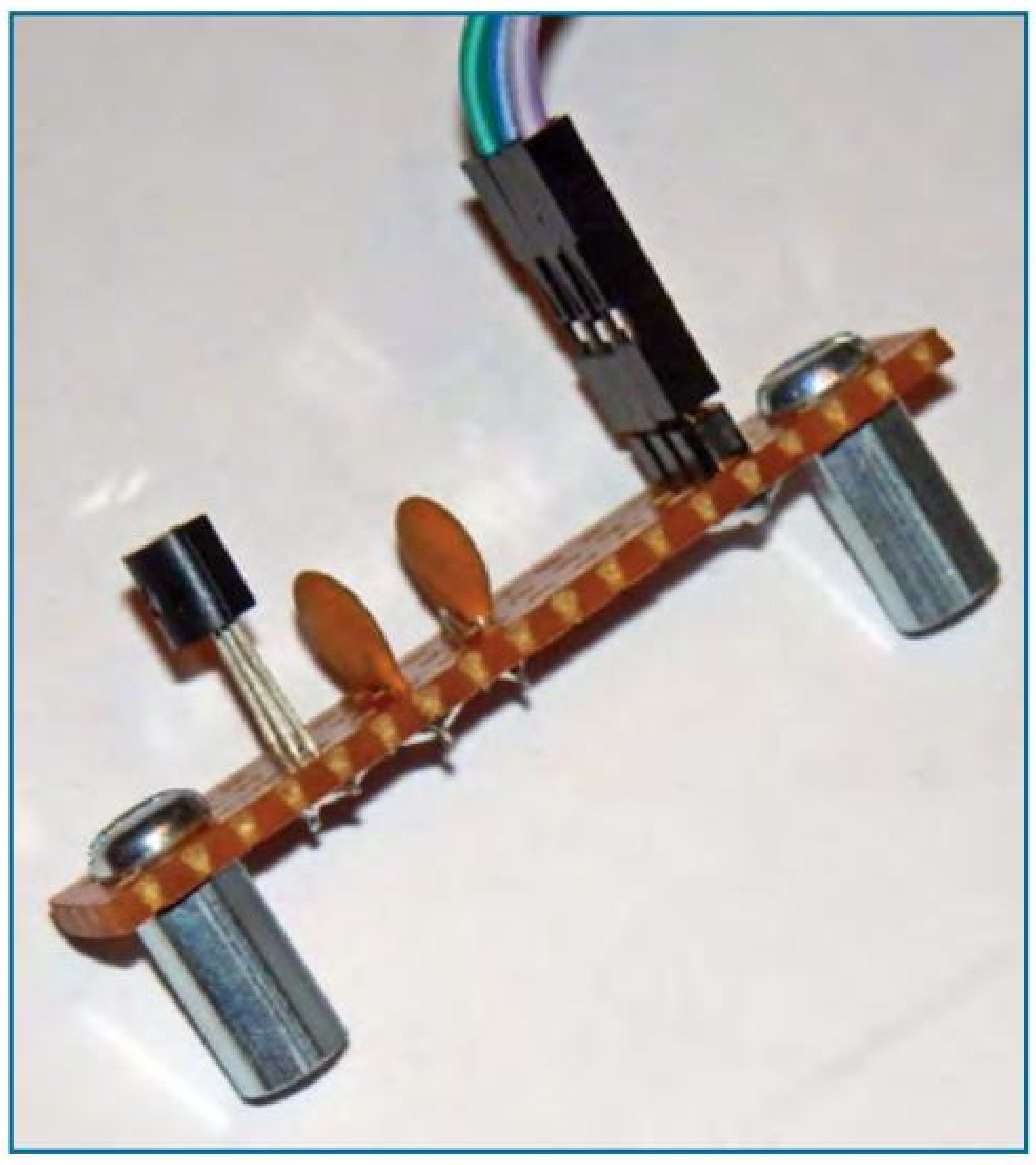


Fig.4.10. The temperature sensor is mounted on a small piece of stripboard so that it can be separated an appropriate distance from the Uno. Note the two 100nF capacitors used for noise and RFI reduction

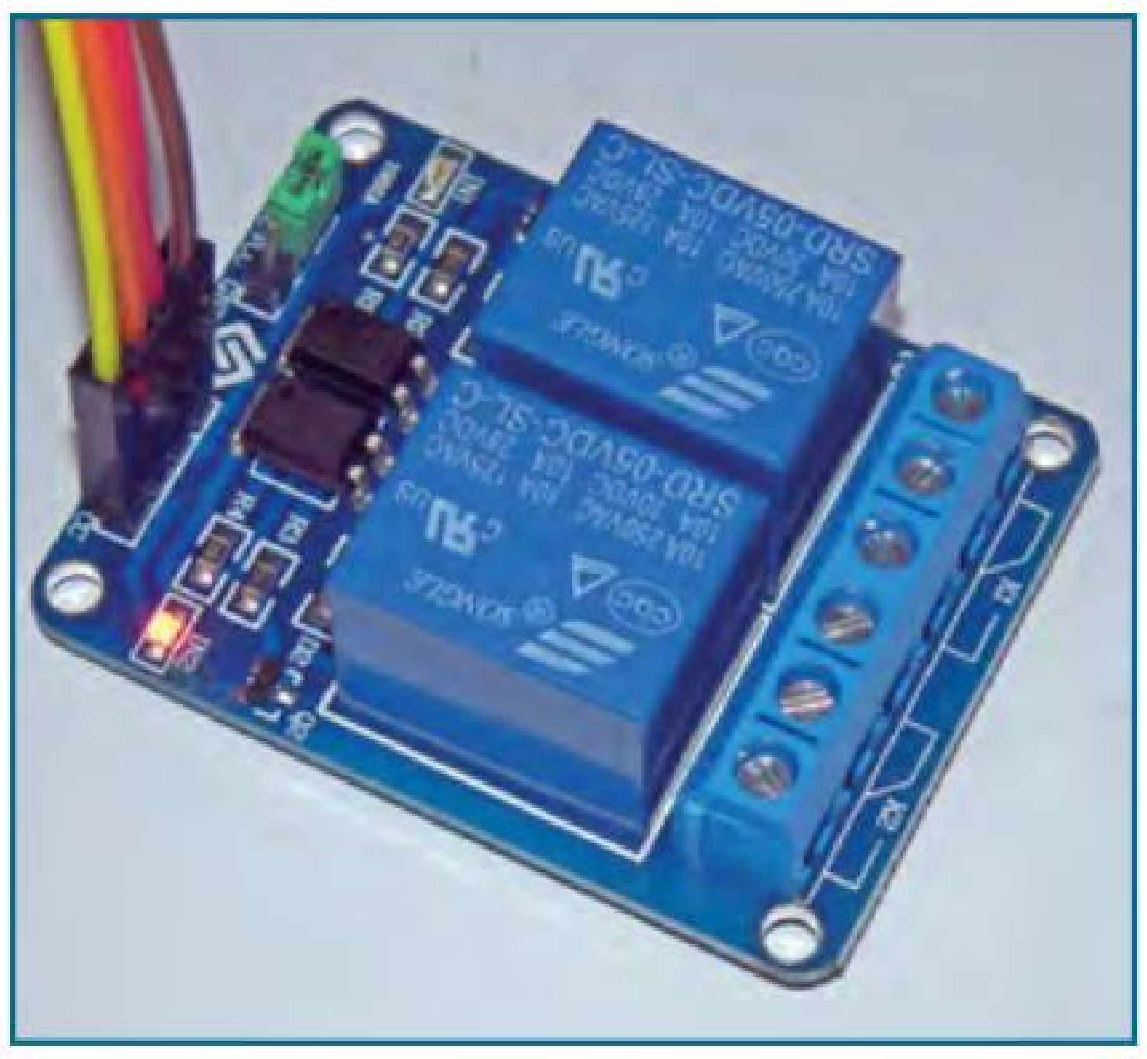


Fig.4.11. Low-cost, two-channel relay board used with the thermostatic controller. The relays are rated for loads up to 10A/250V

Listing 4.5: Code for the simple Arduino Uno based thermostatic controller

```
/* Thermostatic controller based on the Arduino Uno */

#include <LiquidCrystal.h>    // Include the LCD library
#include <math.h>

LiquidCrystal lcd(7, 6, 5, 4, 3, 2);  // I/O pin numbers for the LCD

const int sensor = A0;  // TMP36 sensor connected to analog input A5
const float low = 4; // Low temperature threshold A
const float high = 26; // High temperature threshold B

int relayA = 8;  // Heating
int relayB = 9;  // Cooling

void setup() {
  // set up the LCD's number of columns and rows:
  lcd.begin(16, 2);    // Display has 16 columns and 2 rows
  lcd.print("Temperature:");   // Display a message
  pinMode(sensor,INPUT); // A0 is an input
  pinMode(relayA, OUTPUT);
  pinMode(relayB, OUTPUT);
  digitalWrite(relayA, HIGH); // Start with both relays off
  digitalWrite(relayB, HIGH);
}

void loop() {
  lcd.setCursor(0, 1); // Begin on the second line
  float sensorVoltage, sensorTemperature;
  int sensorValue;
  // Get sensor value and convert to deg.C
  sensorValue = analogRead(sensor);
  // Convert value to voltage
  sensorVoltage = (sensorValue/1024.0)*5.0;
  // Convert voltage to temperature
  sensorTemperature = (sensorVoltage - 0.5) * 100 ;
  // Display the temperature
  lcd.setCursor(0, 1); // Use second line of the display
  // Print temperature of TMP36 sensor
  lcd.print(round(sensorTemperature));
  lcd.print(" ");
  lcd.write(B11011111); // degree symbol
  lcd.print("C ");
  if (sensorTemperature <= low) {
    digitalWrite(relayA, LOW);
    lcd.setCursor(15, 0);
    lcd.print("L");
  }
  else {
    digitalWrite(relayA, HIGH);
     lcd.setCursor(15, 0);
     lcd.print(" ");
  }
  if (sensorTemperature >= high) {
    digitalWrite(relayB, LOW);
    lcd.setCursor(15, 0);
    lcd.print("H");
  }
  else {
    digitalWrite(relayB, HIGH);
    lcd.setCursor(15, 0);
    lcd.print(" ");
  }
  delay(2000); // Wait two seconds
}
```

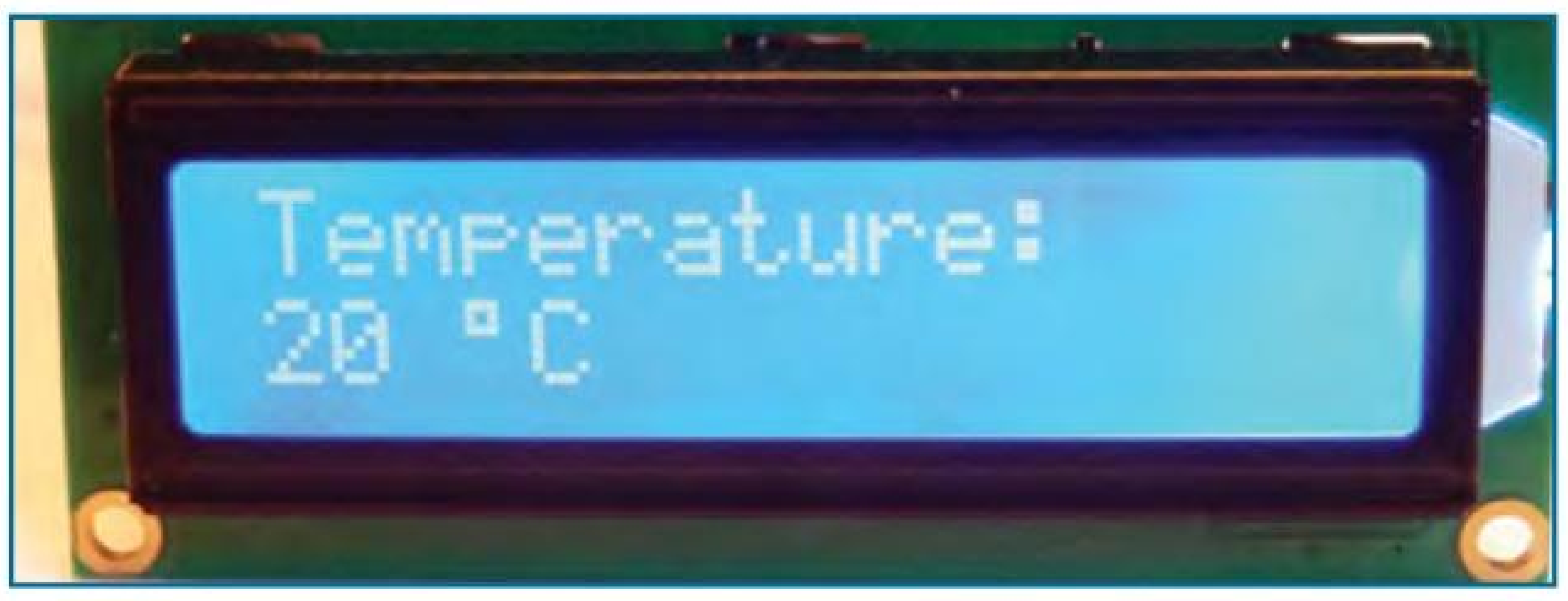


Fig.4.12. Temperature displayed on the backlit LCD

library files was described in last month's *Teach-In 2016*.

Testing

After you've corrected any coding errors that the compiler reports you will be ready to upload your code to the Uno. Just click on the upload arrow and watch the progress report. When the Uno performs a reset you should see the temperature displayed on the LCD (see Fig.4.12) together with 'H' or 'L' if the temperature is respectively above or below the threshold setting.

In some circumstances you might notice that the output switches on and off several times when the temperature falls below the lower threshold. This is due to the increased load on the 5V supply. When energised, the increased current demanded by the relay causes the supply voltage to fall slightly and this, in turn, reduces the ADC's reference voltage. This problem can be resolved using a suitably rated and more closely regulated 5V supply. Alternatively, a separate 5V supply can be used for the relays, in which case the link marked 'Vcc' should be removed on the two-channel relay board and an external +5V connection made at this point.

A better, but slightly more expensive alternative is the use of a two-channel solid-state relay board (see Fig.4.13). This uses no moving parts and only requires a very modest current to drive the relays. Finally, the thermostatic control system requires a reliable 9V DC supply. This could take the form of a suitably rated mains supply (9V at 500mA minimum) or a float-charged battery with an output of between 8V and 12V.

Going further

As usual, there's a great deal of scope for going further with our Arduino-based thermostatic controller. The most obvious enhancement would be the addition of a keypad

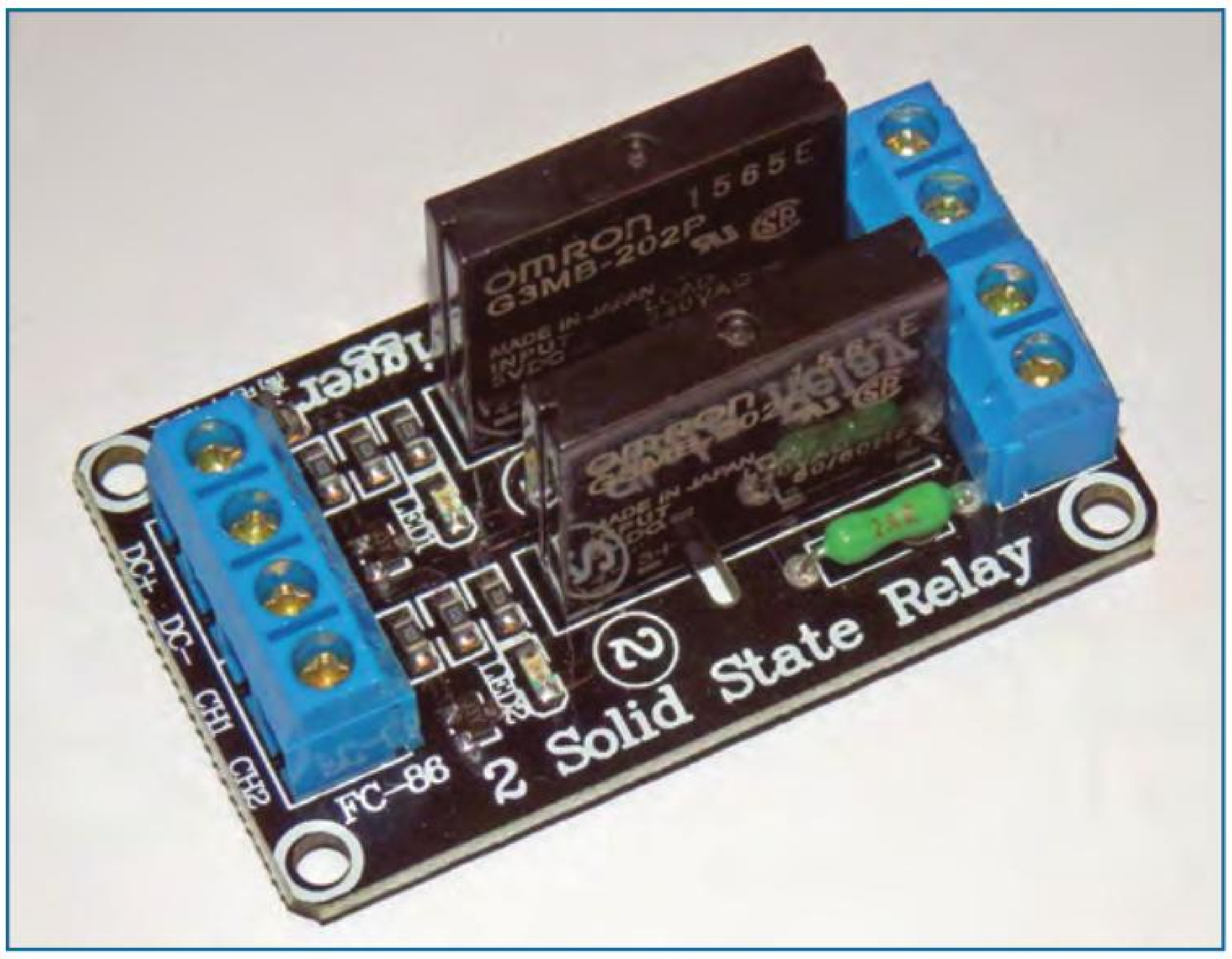


Fig.4.13. A two-channel solid-state relay board

to program the upper and lower threshold temperatures, avoiding the need to have these set in the software. Another refinement might be the addition of a light sensor (using a second analogue input) with an output for a separate relay to control lighting. All of this is relatively simple to do and will provide you with a great opportunity to further develop your coding skills.

Next month

In next month's *Teach-In 2016* we will be looking at ways in which an Arduino can handle multiple sensors using a limited number of wire connections. To this end, *Arduino Workshop* will introduce the highly versatile 1-wire bus system, and *Arduino World* will cover temperature sensors that have their own integrated ADC, offering a much higher resolution than the ADC converters built into the Arduino Uno. Our programming feature, *Coding Quickstart*, will introduce file handling. Finally, our *Get Real* project will take the form of a standalone monitoring system that can capture large amounts of data, conveniently processing and storing it on a conventional SD memory card.

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Practically Speaking

Robert Penfold looks at the Techniques of Actually Doing it!

Switches

THE PURELY mechanical nature of switches makes them one of the simplest and most low-tech of electronic components. Despite this, there is still a certain amount of terminology to master when dealing with switches. It should also be borne in mind that it is not a good idea to be too *blasé* when dealing with switches, since mistakes can be time consuming to fix, cause expensive damage, and could even be dangerous. Practical experience has proved that the obvious method of connection and the right method are not always the same! As with some other types of component, the range on offer seems to have steadily grown over the years, making it easy to buy the wrong thing.

Two-way stretch

Two-way switches are the simplest type, and many of these are designed to provide a simple on/off action. There are more complicated two-way switches though, and these are designed to provide a changeover action, such as switching between one waveband and another, or between high and low sensitivity. The two most popular types of basic switch are the toggle and slider types. A toggle switch is operated via a small lever that is called a 'dolly', and the original toggle switches were quite large by current standards. These standard toggle switches are still available and in use today, but the various miniature versions are more appropriate for most modern electronic gadgets.

A slider switch is the most basic form of switch, and as the name implies, it is moved between its two positions via a small sliding control knob. I have encountered commercially produced equipment that has a three-position slider switch, but these do not seem to be used to a significant degree in hobby electronic projects. Slider switches are relatively inexpensive, but are less popular than the miniature toggle variety. One problem is that some of them seem to be built down to a price, rather than up to a standard. This can lead to reliability problems, with the control knob having to be shuffled around slightly before a proper connection is made. Slider switches usually have rather awkward mounting requirements. A rectangular hole to accommodate the travel of the control knob is required. Making this is not particularly difficult, but making a really neat job of this can be a bit tricky.

There are other types of two-way switch, including the rotary type. These are controlled via an ordinary control shaft and knob, which makes them larger than ideal for small gadgets. They tend to be relatively expensive, especially when the additional cost of the control knob is taken into account. They are mostly of very high quality though, and offer good long-term reliability.

It's biased

Pushbutton switches are another form of two-way switch, and they are available in two basic forms. These are the biased and standard varieties. A biased switch is one that the user sets to one position, but the switch springs back to its original position as soon as it is released. A reset switch is probably the most common application for this type of component, but they have other uses. Biased pushbutton switches are sometimes referred to as 'momentary operation' switches in component catalogues.

Simple pushbutton switches that have two contacts are available in two types, which are the 'push to make' and 'push to break' varieties. The former is the one that would probably be regarded as the standard type. The switch is normally in the open (off) state, and pressing the button results in a connection between its two tags. Things are the other way around with a 'push to break' switch. The contacts are closed (on) until the button is operated. Where no guidance is given in a components list, it can reasonably be assumed that it is a 'push to make' switch that is called for.

It is not only simple pushbutton switches with two terminals that are available with biased operation. It is a feature of some pushbutton switches that have more complex contact arrangements, and some toggle switches also have biased operation. However, these are rather specialist components that are little used in projects. The majority of the more complex pushbutton switches use what is normally termed 'successive operation'. In other words, the switch changes state each time it is operated. In a simple on/off application, operating the switch the first time would switch the unit on, a second operation would switch it off again, a third press would switch it on once again, and so on.

Contact arrangements

With two-way switches you are certain to encounter acronyms such as SPST and DPDT. These describe the contact arrangements of the switches, and there are four basic types of switch. The terms used to describe them and their normal abbreviations are provided below:

Contact arrangement	Abbreviation
Single-pole, single-throw	SPST
Single-pole, double-throw	SPDT
Double-pole, single-throw	DPST
Double-pole, double-throw	DPDT

The simplest of these is the basic on/off switch, or SPST (single-pole, single-throw) switch. This has just two tags with a connection between the tags when it is 'on', and no connection when it is 'off'. A DPST (double-pole, single-throw) switch is basically just two on/off switches combined in a single component and operated in unison. An SPDT (single-pole, double-throw) switch has three tags rather than the two of an SPST type. The middle tag is called the 'pole', and it connects to one or other of the other two, depending on the setting of the switch. A switch of this type is often referred to as a 'changeover switch', and it is used for selecting one or other of two functions. A DPDT (double-pole, double-throw) switch is effectively two SPDT switches in a single case and operated in unison. Fig.1 shows the tag arrangements normally used for the four basic types of switch, and how they relate to their circuit symbols.

Testing, testing

Although the arrangements shown in Fig.1 are the ones used for most toggle and miniature toggle switches, there are some exceptions. Fortunately, the simple nature of switches means that there is no difficulty in testing them using any multimeter or a continuity tester. When dealing with any switch of an unfamiliar type it is definitely advisable to make some tests to determine which tags are connected together at each setting of the switch. Bear in mind that mistakes can have serious consequences, such as short-circuits on the supply lines, or two sets of outputs connected together. Errors such as these could result in damage to components and in some cases they are potentially dangerous.

With toggle switches you must avoid the classic mistake of getting the two positions of the switch confused. It is reasonable to assume that this mistake would soon be noticed if it should happen with an on/off switch, but the problem could be far from obvious with a switch that is used to control some other function. Fig.2 (top) shows the normal on and off positions for single-throw toggle switches. With double-throw switches, the middle and lower tags are connected together when the dolly is in the 'up' position, as in the lower drawing of Fig.2. Due to their very basic mechanisms, slider switches operate in the opposite fashion. The middle and upper tags are connected together when the control knob is in the 'up' position. Once again, there could well be some exceptions to all this. Some checks with a continuity tester can be used to clarify matters before any connections are made, and should avoid any difficulties later.

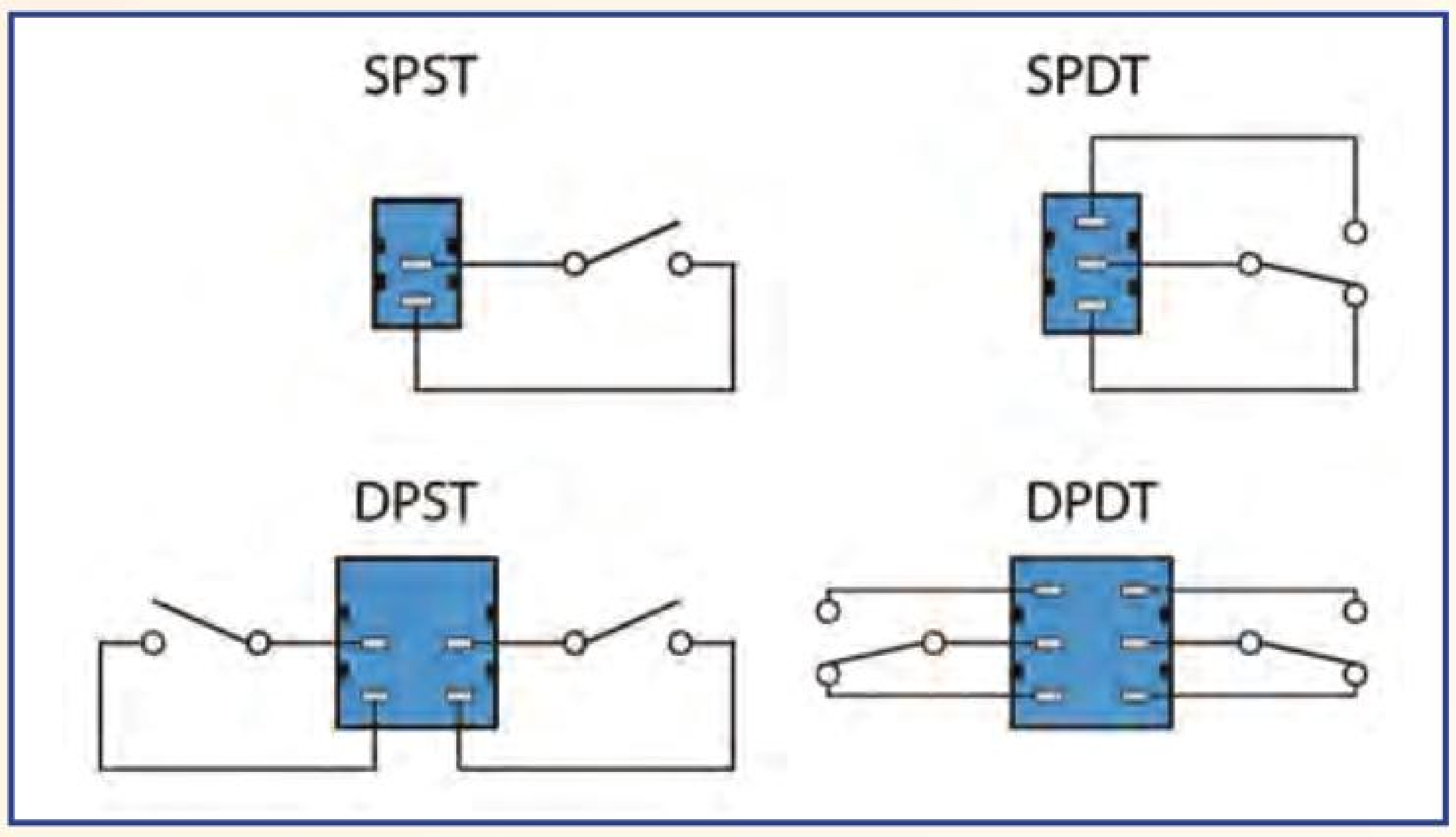


Fig.1. The contact arrangements normally used for the four basic types of switch. There may be some that do not follow this scheme of things – always check!

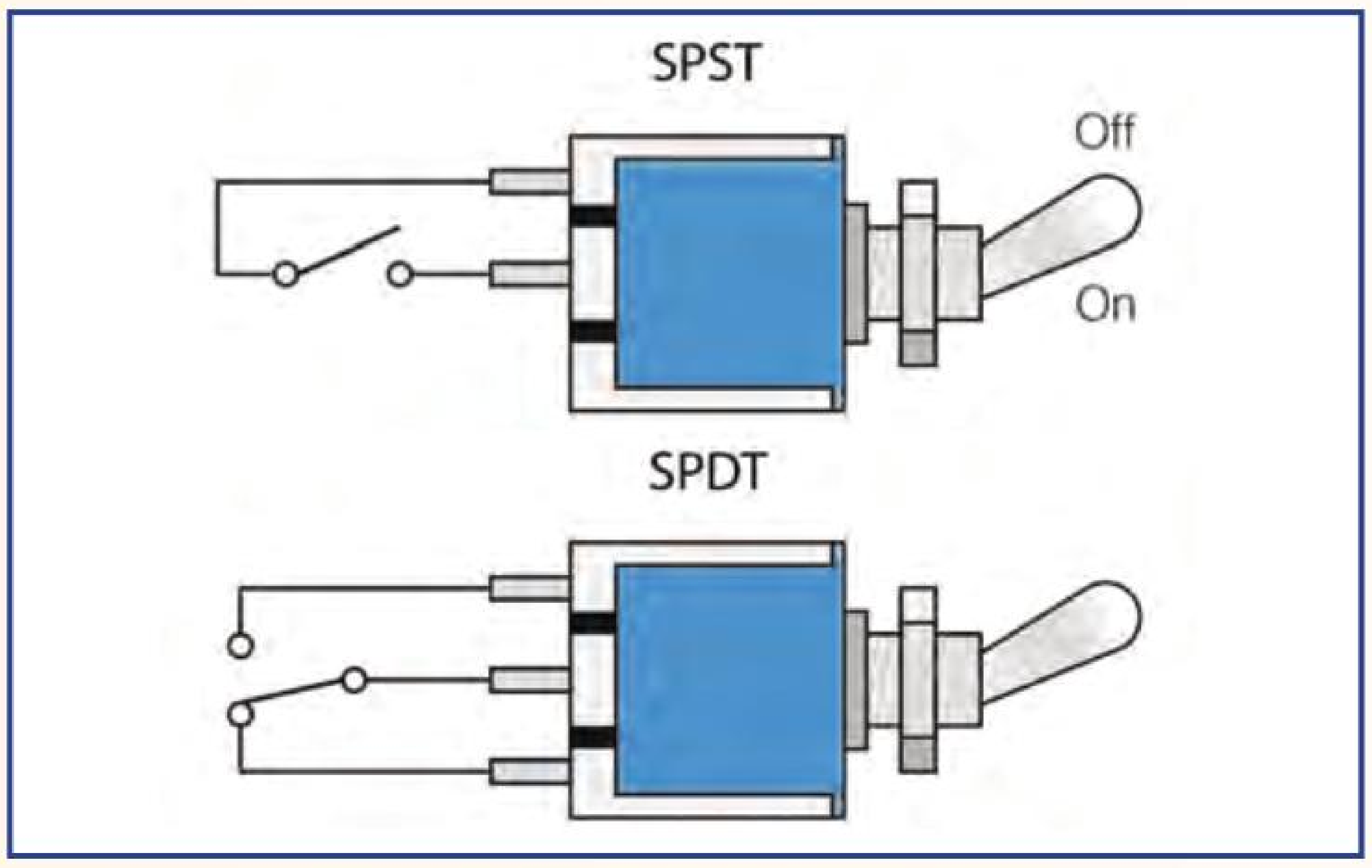


Fig.2. Try not to get the 'on' and 'off' settings of switches confused. If in doubt, make tests with a continuity checker

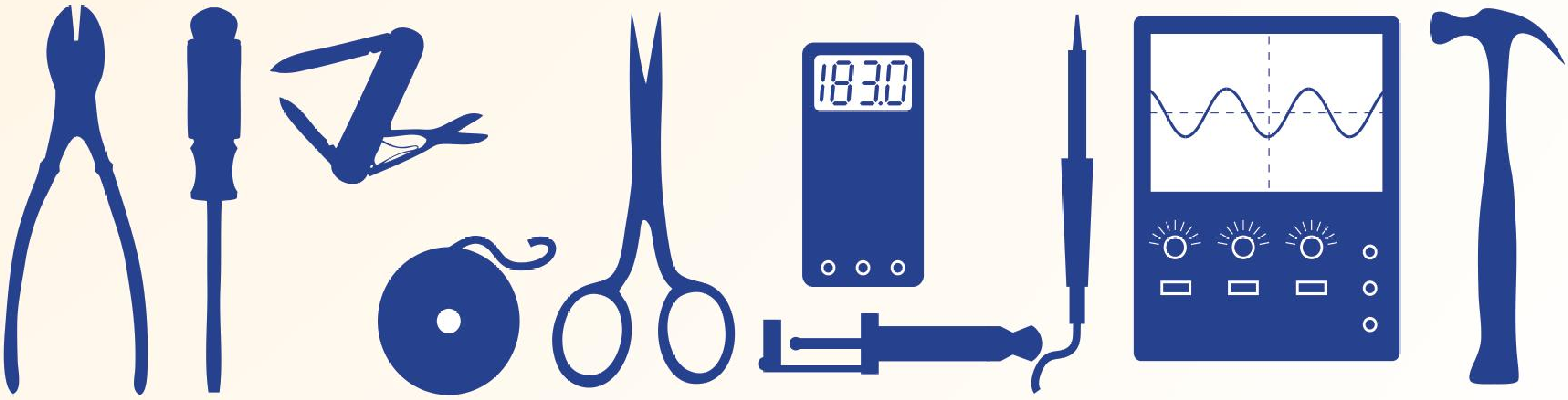
It is only fair to point out that many switches are no longer offered in all four versions. This is presumably due to the rationalisation of many component ranges in recent years, and the fact that one of the more complex switches can be used in place of a very simple type. In fact, a DPDT switch can replace any of the other three basic types of switch. It is just a matter of ignoring any tags that are not required. As an example, if an SPDT switch is required, it is just a matter of using one pole of a DPDT type and leaving the other three tags unconnected.

Although used less than was once the case, it is still possible to obtain so-called 'switched potentiometers'. These have a built-in DPST switch, and are mainly used as a combined volume and on/off control in audio and radio equipment. The physical placement of these tags offers no clue as to the correct method of connection. A few have a connection diagram moulded into the rear of the plastic body, but most do not. Fig.3 should help to clarify matters. With battery powered equipment it is normal for only one side of the supply to be switched, and one pole is then left unused, as in the lower diagram of Fig.3.

More ways than two

The switches described so far are limited to two-way operation, but some applications require something more than this. A radio might have three or four wavebands, or a piece of test gear could have half a dozen or more measuring ranges. The two common approaches to multi-way switching are banks of interlinked pushbutton switches and rotary switches. With linked pushbutton switches, operating a switch automatically deselects the one selected previously. A number of individual switches are thus combined to form a single multi-way type. It is a method that has been much used in commercially produced equipment over the years, but it has never been used much for electronic projects. It tends to be awkward to use and quite expensive.

Rotary switches are the normal choice, and they are widely available in 12-way, 1-pole; 6-way, 2-pole; 4-way, 3-pole; and 3-way, 4-pole versions. All four types look much the same, and the only outward difference is the number of pole tags.



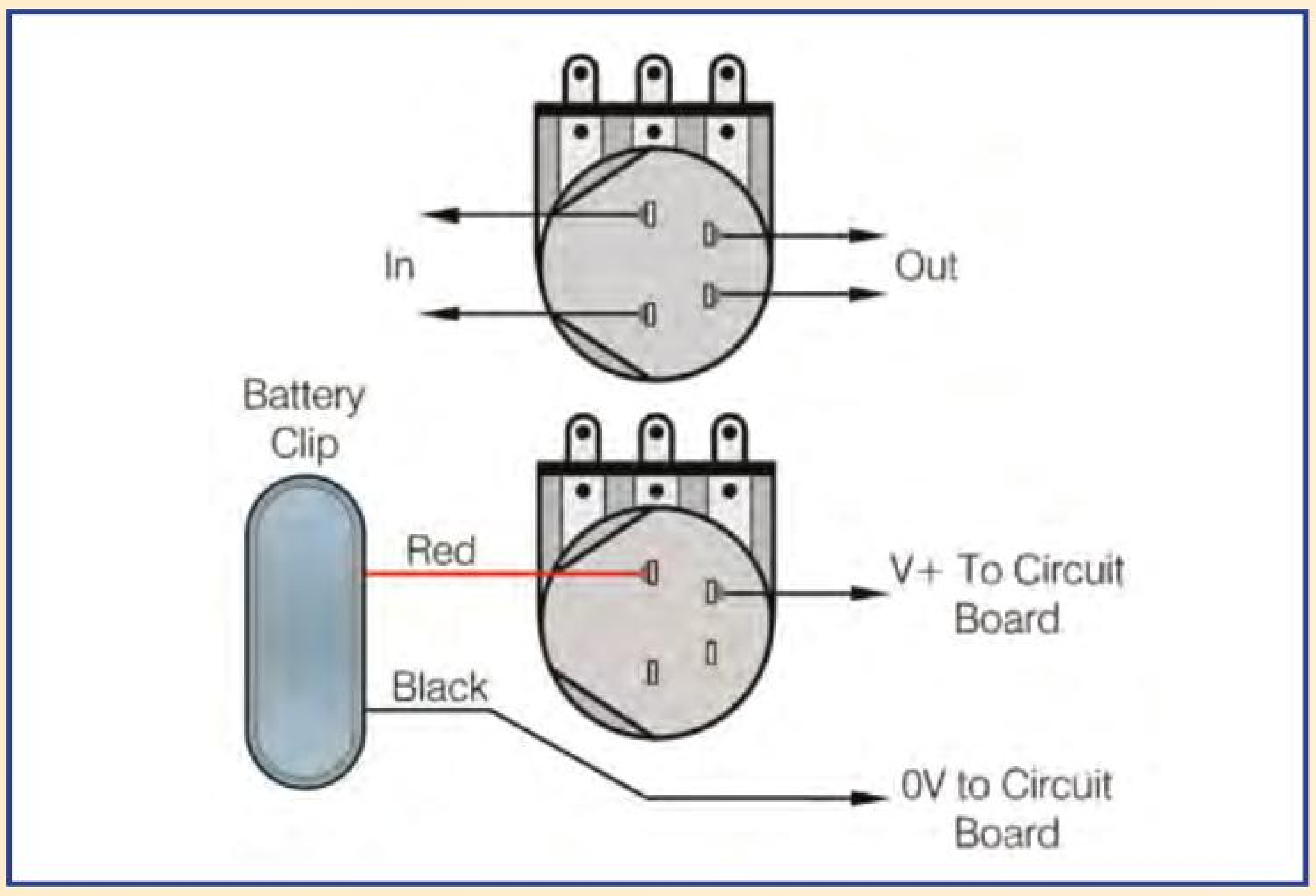


Fig.3. Switched potentiometers usually have a built-in DPST switch. Only one pole is normally used in a battery-powered circuit, as in the lower example

Modern rotary switches have printed circuit pins rather than solder tags, but it is still possible to hardwire them into circuit if necessary. It is more or less impossible to connect them incorrectly if they are fitted onto a printed circuit board, but things are trickier if they have to be hardwired. Modern rotary switches are usually marked with letters and numbers that ease the situation. The pole tags are marked with letters from 'A' to 'C', and the other tags are numbered from '1' to '12', as shown in Fig.4.

Things operate as one would probably expect. With a 4-way 3-pole switch for example, when set fully counter clockwise, tags A and 1 are connected, as are tags B and 5, and tags C and 9. Turning the switch one position in a clockwise direction results in connections between tags A and 2, B and 6, and C and 10. Another turn produces connections between tags A and 3, and so on.

With the tag markings on the switches, and usually included in wiring diagrams, making the correct connections to a switch should be plain sailing. Unfortunately, the markings on the switches are usually quite small and moulded into the plastic bodies of the components. This can make it quite difficult to see them properly, and it is easy to get all the outer ring of wiring shifted one tag along from the correct position. The risk of errors can be reduced by marking the body of the component with spots of ink or paint next to the position-one tags, which would be tags 1, 5, and 9 for a 4-way, 3-pole switch.

Make or break

There are usually two ranges of standard rotary switches listed in component catalogues. The two types are 'break-before-make' and 'make-before-break'. A make-before-break switch still has the pole briefly connected to one tag as it is shifted over to make contact with the next tag. This produces a brief short-circuit between two outer tags as the switch is adjusted from one position to the next. No short-circuit occurs with a break-before-make switch, because the pole is disconnected from the first tag before it makes contact with the next one. However, this results in the pole tag being momentarily left unconnected to an outer tag.

All this might seem to be unimportant, and with many circuits the type of switch used is certainly of no consequence. Unless a components list specifies a certain type, it is in order to user either. Where a specific type is called for, then that type must be used. It is particularly important not to use a make-before-break switch instead of a break-before-make type. Doing so could have dire consequences, perhaps with a brief short circuit on the supply lines each time the switch is moved from one position to the next, or two outputs being connected together.

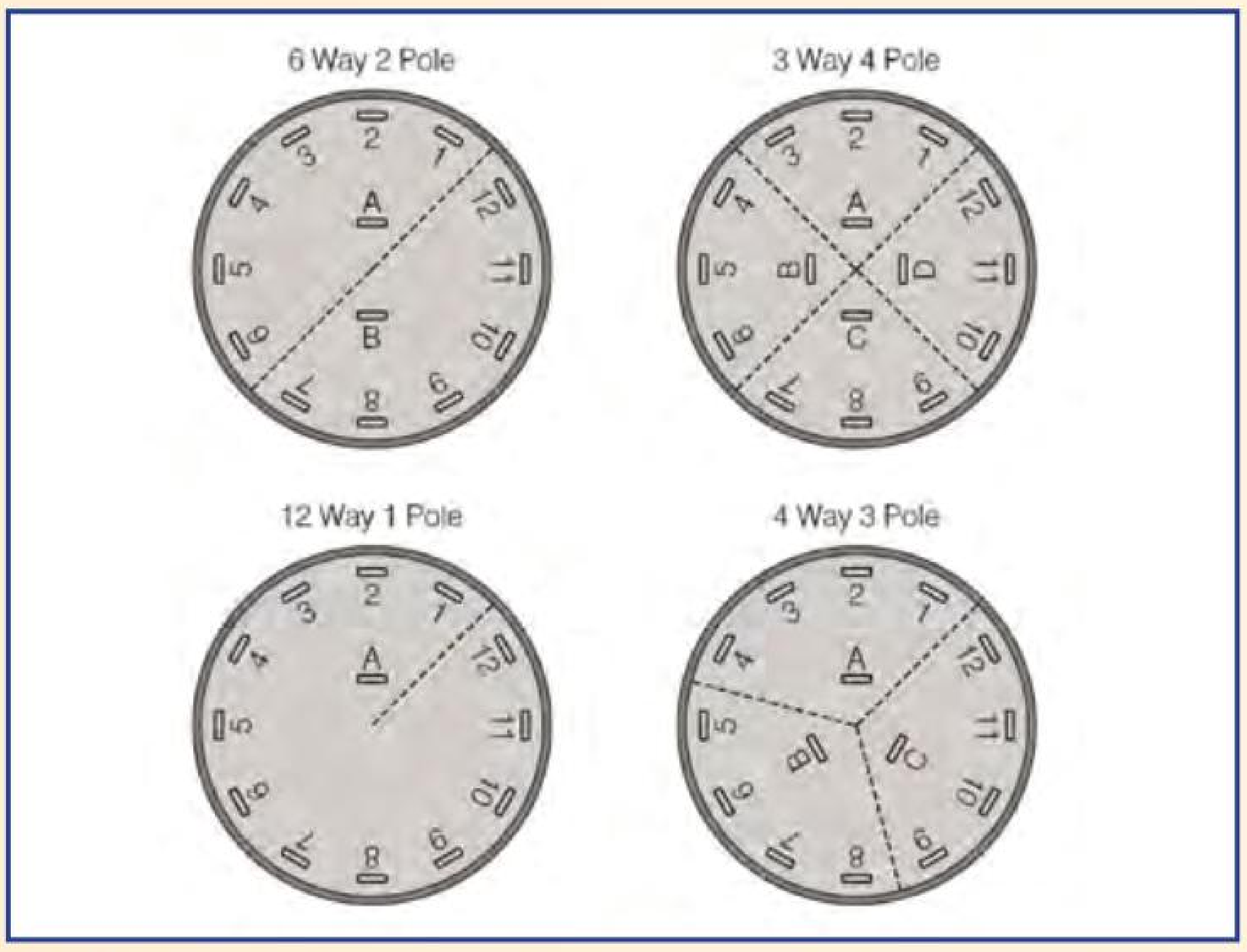


Fig.4. Standard rotary switches normally have the pole pins identified by letters, and the outer ring of pins numbered from '1' to '12'. This helps to avoid wiring errors, but due care still has to be exercised

Set limits

All the standard rotary switches I have encountered in recent years have adjustable end-stops that enable them to be used with less than their maximum number of ways (Fig.5). If (say) a 7-way, 1-pole switch is needed, a standard 12-way single pole switch set for 7-way operation could be used. In some cases, there might be two or three options available. For example, where a 4-way, single-pole switch is needed, one pole of a 4-way, 3-pole switch could be used, with the unwanted sections being left unused. Alternatively, one pole of a 6-way switch set for 4-way operation could be used, as could a 12-way switch set for 4-way use. However, unless you are sure you know what you are doing it is best to use whichever type of switch is specified in the components list.

Final points

Switches are not the most reliable of components, and they will wear out if used a great deal. There can also be problems with corrosion on the contacts if they are left unused for a long time. Simply operating a switch a few times will usually clear the corrosion problem. Contact cleaning fluids and sprays are available and can often help with severe corrosion. However, the closed construction of most modern switches means that there is often no easy way of gaining access to the contacts.

In these days of low voltage, micro-power circuits, the maximum current and voltage ratings of switches are not usually of any practical importance. However, it is something that has to be checked when dealing with circuits that use relatively high currents or voltages. Most miniature switches are not suitable for use with anything more than quite modest currents or voltages. The contacts often have separate AC and DC ratings, with the AC ratings usually being the lower of the two, so make sure that you refer to the right set. This is especially important when using switches in mains-powered circuits, such power supplies or appliance switching operations.

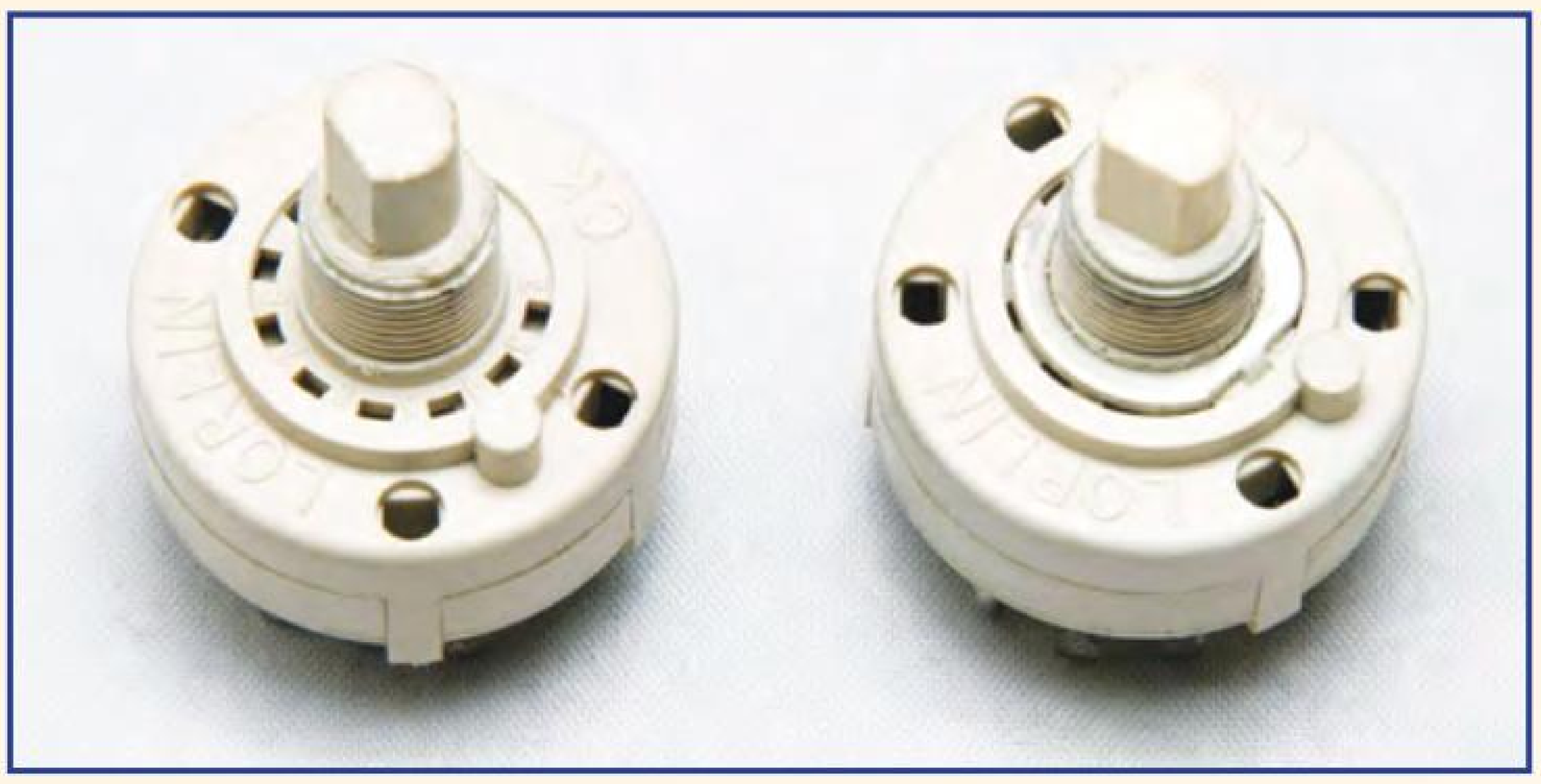


Fig.5. These days, standard rotary switches normally have an adjustable end-stop. It has been removed from the switch on the left, and in the switch on the right it is set for 4-way operation.

NET WORK

by Alan Winstanley

Power hungry

WELCOME to this month's *Net Work* – the column dedicated to bringing you news of Internet developments and current trends. I mentioned last month how the growth in cloud computing has seen data centres springing up in the most unlikely places around the world. To serve the spiralling demands of Internet users, enormous server farms filled with racks of hot equipment have brought with them the problems of energy efficiency and thermal management. Instead of relying on power-hungry chillers and water cooling towers, some imaginative attempts are being made to power them with green energy and cool them using naturally renewable resources. I previously highlighted a new Icelandic data centre that takes advantage of Iceland's chilly climate to help keep its racks cool. The idea of drawing outside air in to cool data centres (so-called 'free-cooling') is not new – Microsoft, for example, built such a data centre in Ireland back in 2009, and in 2011 Google also arrived and converted a Dublin warehouse into an air-cooled data centre of its own.

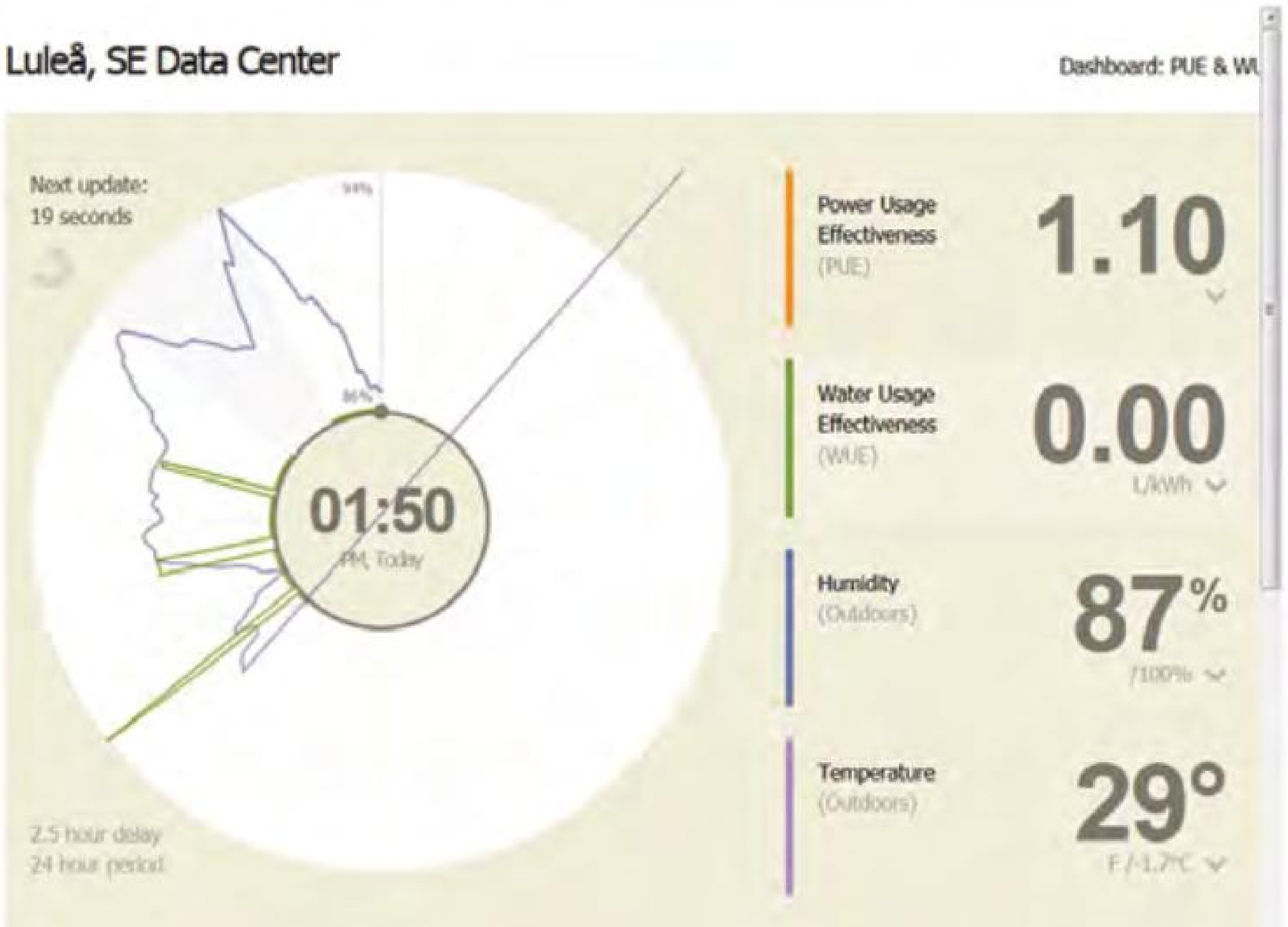
The engineering side of social media giant Facebook has also been extremely active in building its own sustainable data centres, more recently with a site located on Sweden's northeast coast. The company has a stated goal of powering 50 per cent of its infrastructure with green energy by the end of 2018, and their Luleå data centre, north of the Baltic sea, was built in 2013 as the company's first such development outside the US. Facebook spawned the Open Compute Project (OCP) in order to share its technologies on a market-disrupting open-source basis (see **www.opencompute.org**), an altruistic move designed to promote energy-efficient hardware and control systems with no expensive intellectual property strings attached. The first 300m-long server building in Luleå claims to be one of the most sustainable data centres in the world, and its location means that all its power needs are generated locally using 100 per cent renewable and highly reliable hydro-electricity, which means that fewer backup generators are needed. The data centre sucks in ambient air from outside and filters and humidifies it to prevent static build-up, before blending it with the hot air generated by aisles of equipment racks. Warm air is recycled and blended to cool the IT equipment again.

Facebook's Luleå data centre in Sweden depends on hydro-electricity and ambient 'free-cooling' air (Photo: Facebook)

A second building – Luleå 2 – is now under way using Facebook's latest 'Rapid Deployment Data Center' (RDDC) concept. Modules arrive in truck-friendly kit form to reduce the need for on-site construction work, meaning pre-fabricated data centres could be built anywhere in the world that a truck can go. Building architects and surveyors might be interested in the background of Facebook's RDDC at: **www.opencompute.org/blog/faster-leaner-smarter-better-data-centers**. A third building is promised at Luleå, bringing the site's total power consumption to 120MW.

The power of PUE

The current scale of technology and engineering prowess on show in Luleå almost beggars belief, and *EPE* readers will find Facebook's video tour of its Swedish data centre fascinating. More details are at: **https://www.facebook.com/LuleaDataCenter** (you do need a Facebook login to view it). You can now also view the actual performance of Facebook's data centres using online monitors. A data centre's 'power usage effectiveness' (PUE) compares the total power consumed by the data centre with the amount of power delivered to the server aisles themselves. An ideal but impossible 100 per cent efficiency would mean a PUE of 1.0; everything consumed by the data centre being used by the server systems themselves. Another metric, 'water usage effectiveness' (WUE), goes some way to comparing a centre's water consumption against power delivered to the server racks (especially if they use water cooling



Luleå, SE Data Center

Dashboard: PUE & W

Next update:
19 seconds

01:50
PM, Today

Power Usage Effectiveness (PUE) 1.10

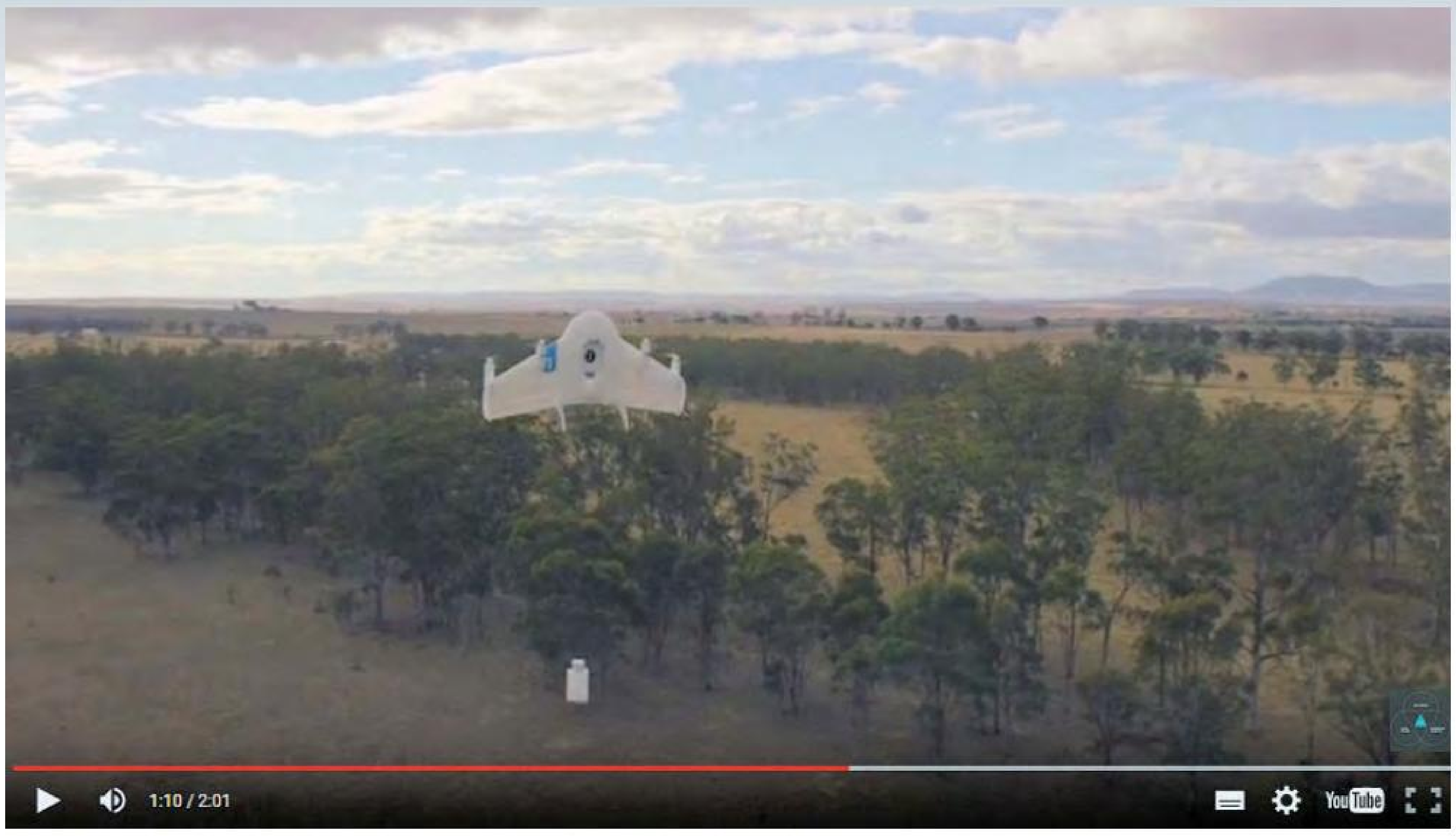
Water Usage Effectiveness (WUE) 0.00 L/kWh

Humidity (Outdoors) 87% /100%

Temperature (Outdoors) 29° F /-1.7°C

2.5 hour delay
24 hour period

Real-time app monitoring of 'power usage effectiveness' (PUE) at Luleå. An ideal but impossible PUE value would be 1.0, or 100 per cent consumption by the server racks of the centre's power demands



Google's Project Wing is an experimental flying vehicle that could deliver small packets semi-autonomously

towers). Facebook's dashboard 'apps' can be accessed in near real-time under the APPS heading found on each data centre's Facebook page. Other Facebook data centres located at Prineville, Oregon and Forest City, North Carolina show a PUE of 1.06 and 1.09 respectively at the time of writing, and Luleå 1 managed 1.05 at one stage. Online seller eBay's servers use fuel cells powered by natural gas, and it applies its PUE ratings to figure out the cost of eBay transactions per kWh, aiming to reduce costs and increase profits by improving the PUE.

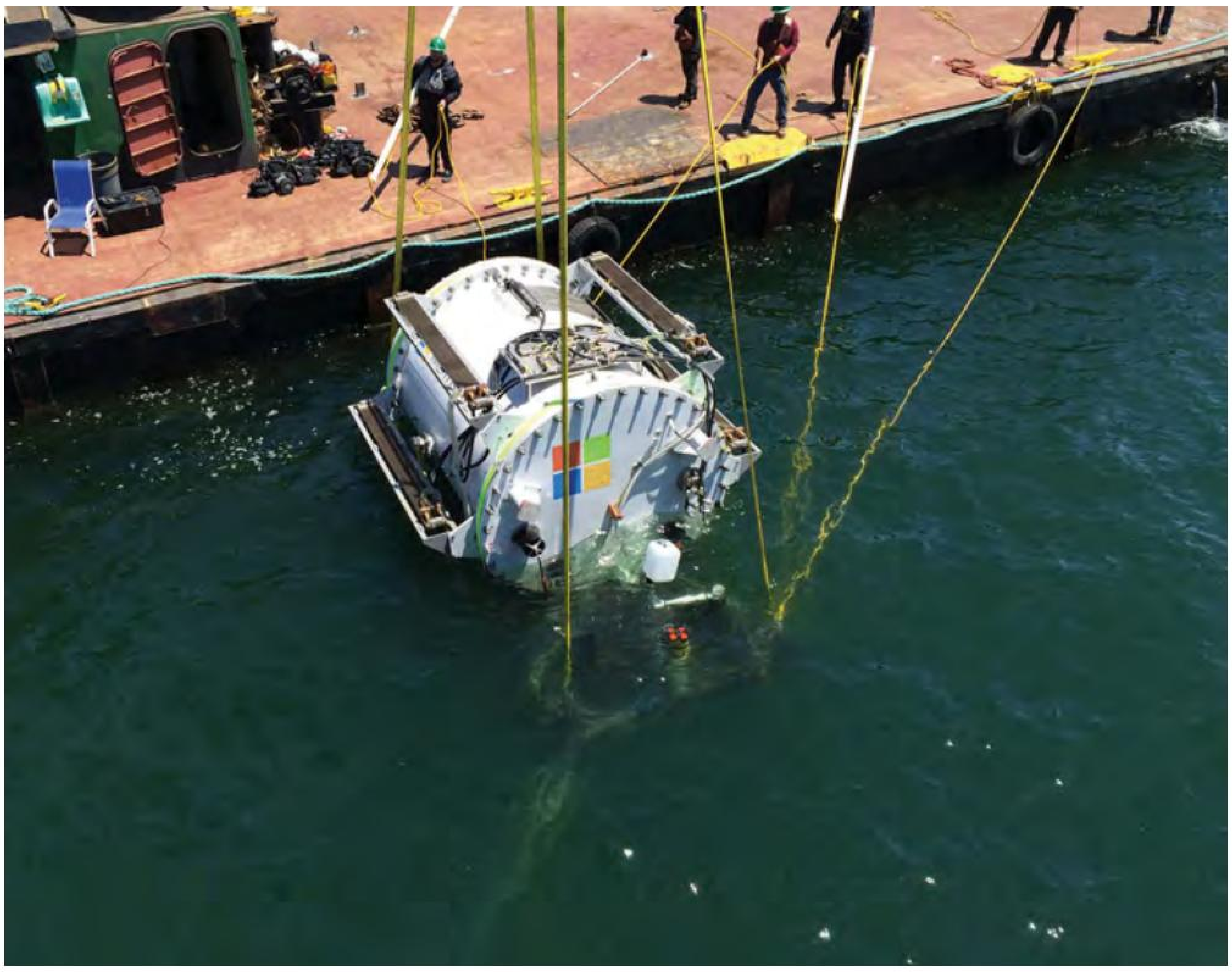
Since opening its first overseas server halls in Sweden, Facebook has started building its second European data centre, this time in Ireland. A new site at Clonee, north-west of Dublin in Ireland will draw on wind-generated Irish electricity and it processes the ambient air intake to eliminate any corrosive salts collected from the Irish Sea. As Facebook's RDDC model continues to be refined, no doubt other impressive data centres will spring up around the world, all as a result of social network users wanting to make themselves heard and 'friend' each other.

Microsoft is developing its own ideas for sustainable data centres too, and as an alternative to using chilly Scandinavian or Irish air to cool them, it is 'plumbing the depths' out at sea. Microsoft's Project Natick is a work-in-progress that is testing the feasibility of submersible data centres. Its first 'data centre vessel', dubbed *Leona Philpot*, was dropped onto the Pacific seabed for a few months in 2015, before being returned to Redmond for assessment. A Natick capsule could quickly be deployed at sea to build a new network at short notice, but before this dream is realised there are many challenges to overcome, including the thorny problem of how to actually power them using, for example, wave or tidal power. More details are at: **www.projectnatick.com**

In an effort to extend Internet access to the least accessible corners of the world, Google's 'Project Loon' aims to form an aerial LTE network using balloons located 20km above Earth, in the planet's stratosphere. This would allow Internet access using mobile phones and other LTE devices. Since balloons tend to drift around, special software would help balloons to counteract any prevailing stratospheric winds and navigate to the right location to maintain the network's integrity. This idea hails from 'X', Google's forward-thinking labs that also hope to bring us driverless cars and Project Wing, the codename for Google's self-flying vehicles that might one day be used as delivery drones. These are undergoing early testing in Australia, where they could perhaps deliver small packets to inaccessible regions such as the Australian outback. Google's 'X' projects can be found at: **https://www.solveforx.com**

Staying vigilant

I constantly preach the need to be vigilant when dealing with websites and email. A common way of attacking a user's system is to send an innocent-looking file attachment (eg, an invoice or a courier advice note) in the hope that the recipient will open it. These are usually easily spotted but potential disaster is still only a click away as a very damaging ransomware virus can be unleashed onto a victim's files, which can become encrypted and a hefty payment in Bitcoins is demanded to unlock them again (if you're lucky). Infected file attachments are normally disguised as a PDF, **.zip** or **.doc(x)** file. Typically, a **.zip** file contains a nasty **.js** (Javascript) file that will create havoc if unleashed onto a user's computer, or it may contain a nasty **.scr** (pseudo screensaver) file. A PDF document might contain a hyperlink pointing to a fraudulent website.



Microsoft's Project Natick is exploring ways of installing small data centres under water

Right on cue, at the very moment that I typed the preceding paragraph, two emails arrived with **.zip** attachments containing a malicious Javascript file that Demon Internet's mail systems had allowed through. All manner of banking Trojans, keyloggers and ransomware can infiltrate a system this way. A suspicious **.doc(x)** file might try to run a macro in Microsoft Word or Excel, and a helpful pop-up even implores users to enable macros to view the document! In turn, it could load an **.exe** file in the background and the damage will be done. These VBA (Visual Basic for Applications) attacks are making a comeback; they seem to come in waves and a handful of dodgy-looking emails will arrive in quick succession. In Microsoft Office, macros can be disabled from running automatically, typically by selecting Word or Excel Options / Trust Center / Trust Center Settings.

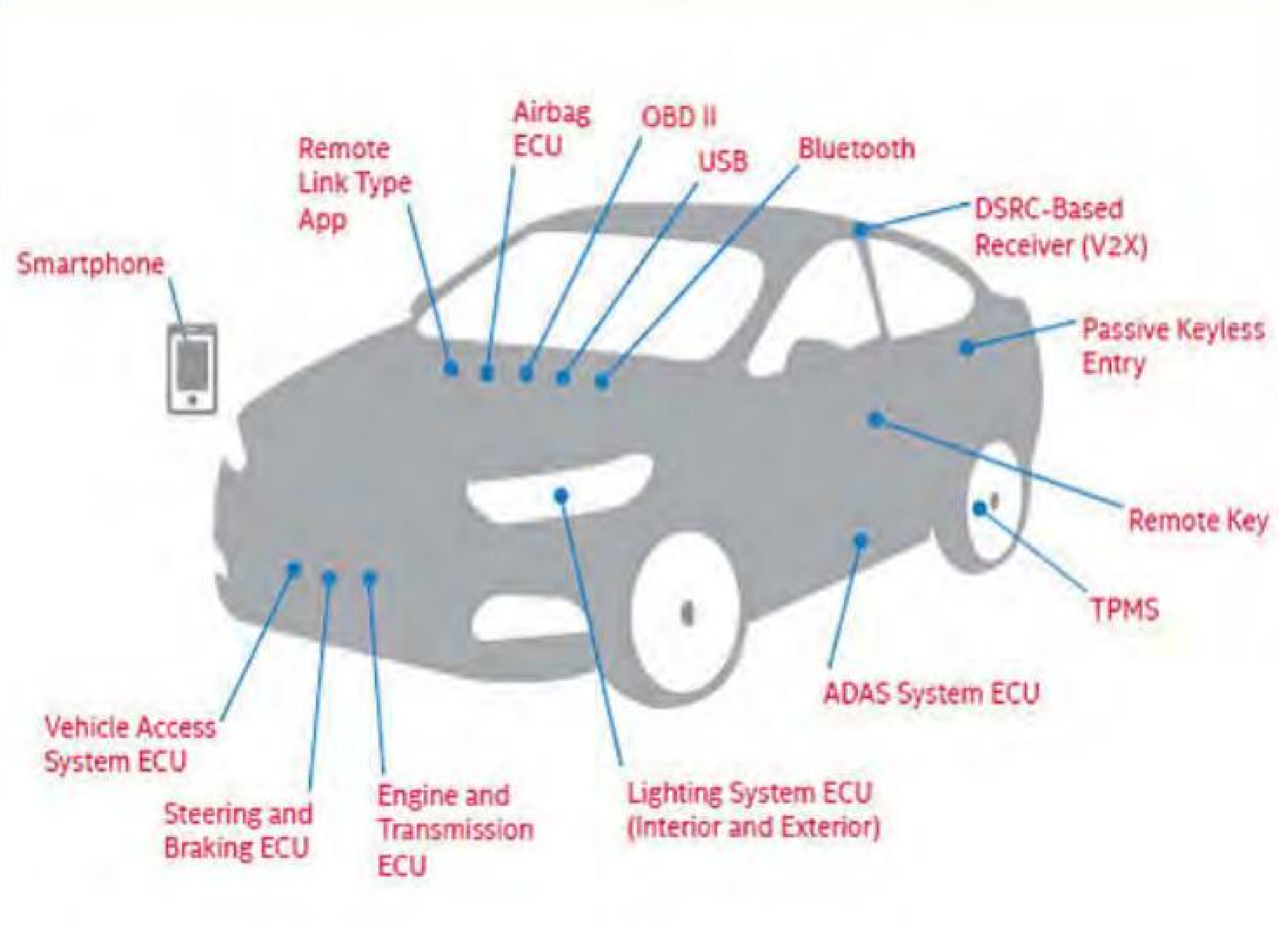
Another tactic being used is to send a supposed 'invoice' as an **.rtf** file attachment, and an average office worker may not know that a Rich Text Format file will probably launch Microsoft Word by default. Overnight, more than a dozen of these phony RTF emails were sent to several of my addresses, and furthermore these file attachments could also be fetched onto a tablet or smartphone where they can lurk menacingly until deleted manually – something else to worry about.

Insecure feelings

Recently, the author received yet another email demanding payment of an attached 'overdue' invoice. This particular email differed from run of the mill ones as it included my name, business details, email address and phone number – all quite authentic-looking stuff. The sender of the email was apparently a hotel. This was an example of a 'spearphishing' attack, with someone's address book or database having been stolen and contact details had been 're-purposed' to send a phony phishing email that targeted specific individuals. Well it nearly had me fooled – but not quite.

Anti-virus and security firm McAfee is now part of Intel Security and the McAfee blog offers a deep and often disturbing insight into current and future network security trends. Last year, McAfee published *The Hidden Data Economy*, a report which painted a frightening picture of how personal and financial data, website logins, enterprise databases, social security numbers and more are stolen, farmed, curated and sold on the dark side of the web. Entire profiles of individuals are on sale to criminals, who can pick and choose how much information they want to buy. Talk about honour among thieves: as a sign of true perversion at play, some of them offer 'honest and guaranteed' data products backed by 'positive feedback from satisfied users' (also scammers). You can read the full report at: **http://preview.tinyurl.com/nq9s9rf**

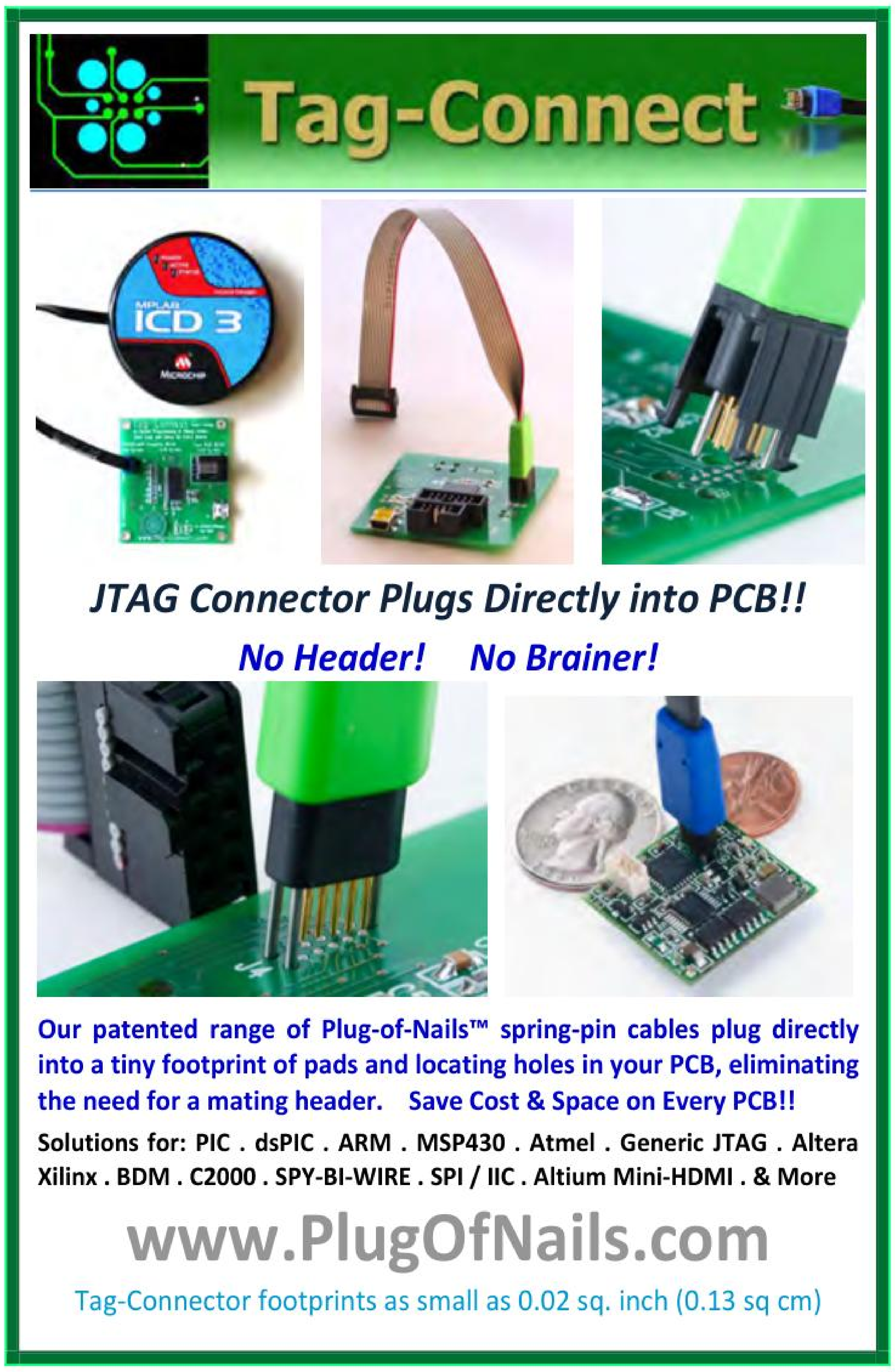
This year, five of McAfee's security experts predicted the top threats that the Internet-related sector would face in the next five years, and their somewhat dystopian conclusion made for alarming reading. They noted that network boundaries have changed to become 'outside-in': tablets, smartphones and notebooks now point outside to the cloud, rather than to a hard-wired local network that can be secured more robustly. Microsoft Office 365, the cloud-based service, may have been the tipping point that kick-started the mass migration to the cloud, they felt. 'At the same time, a strange combination of privacy expectations while intentionally or unknowingly sharing too much will drive the debate over privacy control and regulation,' they observed. McAfee Labs predicts that the Internet will have four billion users by 2019, with the number of IP-connected devices increasing by 50 per cent to 24 billion by then. Hardware-level attacks on silicon itself (eg, the BIOS of a PC or solid-state drive firmware – which remains undetectable despite reformatting or re-installing an OS) will increase and over-the-air updates to keep defences up to date will become a very commonplace feature of life on the 'net. Expect the growth of Internet-of-Things (IoT) hardware to attract the attention of hackers. Ransomware attacks will become even more devious, silently working in the background to encrypt files, and also encrypting their backups, until the attacker pulls the trigger and demands money. They target wealthy countries where users will be happier to stump up the hard cash. Mac OSX is also likely to become a focus due to its increased popularity.



Fifteen vulnerabilities highlighted by McAfee in a typical next-generation network-aware car (Graphic: Intel Security).

Worryingly, McAfee adds that attacks on automobile systems will rise dramatically in 2016 due to the lack of fundamental security in network-ready vehicles, and 'smart highways' may also be prone to hacking with the possible loss of life not far away, they predict. The report illustrates fifteen of the most vulnerable 'attack surfaces' on next-generation networked cars. A demonstration last year showed how a network-aware Jeep Cherokee could be hacked and taken over remotely. It prompted Fiat Chrysler to recall 1.4 million vehicles for a software patch, but these cars can also be patched over the web(!) by typing in the VIN number and downloading the file onto a USB key. In the future, will anyone actually 'brick' their car or infect it with a virus when trying to patch it this way? One thing's for sure, interesting times are ahead as our dependence on networked technology tightens ever more. The McAfee PDF report can be downloaded from: **https://blogs.mcafee.com/mcafee-labs/webcast-experts-explain-mcafee-labs-2016-threats-predictions**

That's all for this month's *Net Work*. You can contact the author at: **alan@epemag.demon.co.uk**



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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

Choosing and using accelerometers – Part 2

THERE'S BEEN some discussion on the *EPE Chat Zone* forums comparing development with Arduino controllers versus PICs. While I'm not going to compare one with the other, I did find that one of the most important discussions from the forums was the ease of building projects with an Arduino compared to PICs. I guess it's good to compare how hobbyists and professionals build prototypes using breadboards and through-hole components. Electronic components continue to shrink and the smallest surface-mount devices are well-nigh impossible to 'throw together'. This is certainly one of the reasons why Arduino boards have become so enticing. The Arduino offers a beautifully easy form factor, in which you can plug various different sensors and quickly get started with a huge software library. On the other hand, I do like to design my own PCBs that allow hobbyists and professionals alike to quickly build a project with any sensor already on the market – but that's a discussion for another day.

Spirit level

Last month, we examined two accelerometers; how they work and what we can do with them. Here's a fun project to demonstrate the operation of our accelerometers – an accelerometer-based electronic spirit level. So, what do we need to achieve this? An electronic spirit level needs a display that tells us that it is level or not level. A series of five LEDs should do the job nicely. The centre LED will be our balance point. I'm also going to add a small buzzer that makes a sound when the level is unbalanced. It will be visually and aurally enticing – but simple enough to construct quickly.

For this project, we only need to look at one axis, and I chose the *x*-axis. When we place our accelerometer up against the wall, with our *x*-axis parallel to the ground, we should be able to detect the change in our acceleration as we tip it left and right. By tipping it right, we want our LEDs to light up to the left, thus indicating rotation to the left in order to balance, and vice versa.

Components

PIC18F27J13 (we will use one in the *LPLC Board* from: **www.mjhdesigns.com**)

5 × Green LEDs
5 × 330Ω (current-limiting resistors)
1 × buzzer
1 × 9V PP3 battery
1 × LD1117 low drop-out (LDO) voltage regulator
1 × PP3 battery connector
PICkit 3 programmer

Alternatively, for power you can use two AA batteries in a battery box instead of a 9V battery and LDO regulator.

Implementation

This is a PIC project, so naturally it's all about the software. I'm going to use the code I used to finish off the *LPLC Oscilloscope* project back in the October 2015 edition. This piece of code contains all the major functions we'll need, including timers and ADC capture functions. I'm going to cut out all the previous functions regarding the TFT screen and add new functions described below.

First, we need to know what is the received value from the accelerometer that indicates it is balanced? In order to find this out, we must look at the range we're expecting. Our voltage into the PIC18F is 3.3V and the PIC's internal ADC operates at 10-bit resolution. This means there are 10 bits to describe the varying voltage levels between 0 and 3.3V. Since we're working with binary, we get 2^10 = 2^{10} = 1024 bits in total. So if our ADC returns 0, our voltage is 0V, if it returns 1023_{10} = 11 1111 1111_2, we have 3.3V and that includes everything else in between. What does this really mean for our output from the accelerometer though?

Looking at Fig.1, we see our three-axis accelerometer. We're only interested in output from the *x*-axis, so we are going to ignore the other two accelerometer axes. In Fig.1 a), we see our *x*-axis is parallel to ground, and perpendicular to the Earth's gravity and hence there is no force due to gravity acting along the accelerometer's *x*-axis. This is our balance point, where the gravity component is acting along the accelerometer's *z*-axis and at right angles to the accelerometer's *x*-axis. Since there is no *x*-axis force, the output is zero. In Fig.1 b) we apply a slight tilt to our device. Now gravity is partially acting along the accelerometer's *x*-axis because it is no longer parallel with the ground. The resulting force on the accelerometer's *x*-axis is the value we'll be measuring to make our spirit level work. If we tilt it the other way, it will be in the opposite direction along the *x*-axis

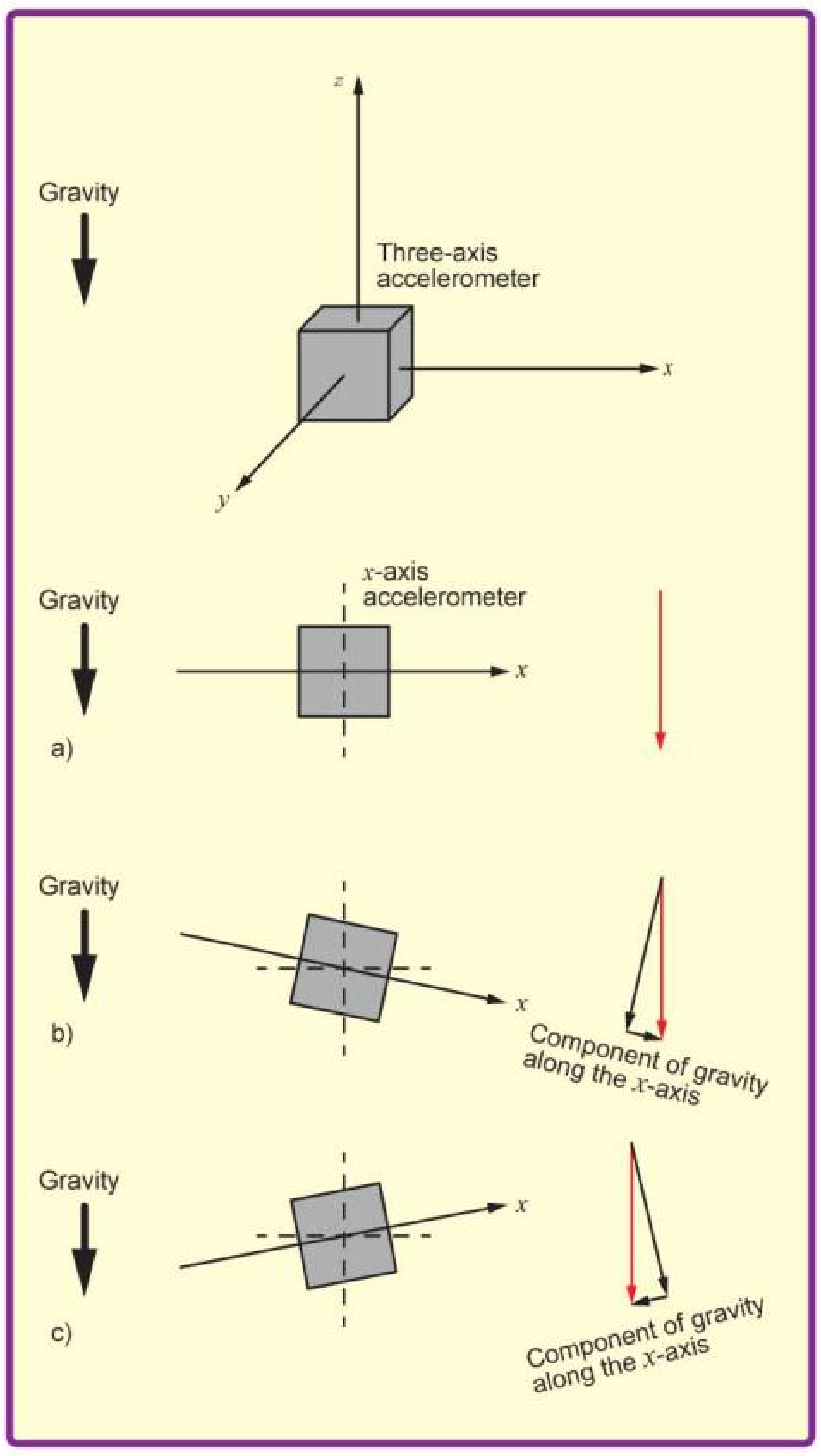

Fig.1. Our digital spirit level in three-dimensional space – in this project we are ignoring the y *and* z *axes. a) When the accelerometer's* x*-axis is perpendicular to gravity the device experiences no force along the* x*-axis and we have the balance point; the sensor's output is exactly half the supply voltage. b) If the accelerometer's* x*-axis is rotated so that it is no longer perpendicular to the direction of gravity then it will experience force along its* x*-axis. Notice that the direction of the force depends on the direction of rotation.*

and will give us a negative signal. From the datasheet, we are told that when the *x*-axis is balanced, it will output half of the input voltage, which is 3.3V divided by 2 = 1.65V. This will be read on our ADC as 1023 divided by 2 = 511.5 So, strictly it's speaking halfway between two values: 512 = 10 0000 0000$_2$, and 511 = 01 1111 1111$_2$. We'll use 512 – so, tilting the accelerometer in one direction will cause the output to rise and hence the ADC will output more than 512 bits, and the tilt LEDs will indicate in one direction. Tilt in the other direction and the ADC output will fall below 512 bits, and the other tilt LEDs will light up.

We need to use an interrupt to grab a sample from our ADC every time it's ready. We can see this software flow in Fig.2 (I created the original using Lucidchart software – well worth a look if you need to create this kind of diagram). Our PIC software only really needs to know whether the accelerometer's *x*-axis output is increasing or decreasing, and by how much. Then we need to think about how sensitive it's going to be and decide between what threshold values the level is balanced. Plus, at what point the software will light the first outer LEDs (next to the centre) and at what point it will light the endmost LEDs.

Let's go with 10 bits of difference to start off with. So, if our input value is less than 512 – 10 = 502, we light our first LED to the left. If it moves beyond 512 + 10 = 522, we light our first LED to the right. Likewise, if we move beyond 512 – 20 = 492 or 512 + 20 = 532, then we light up an endmost LED.

See Fig.3 for our circuit schematic. The *x*-axis on our accelerometer is the only signal connected because we don't need the *y* and *z* axes for this project. Our LEDs are

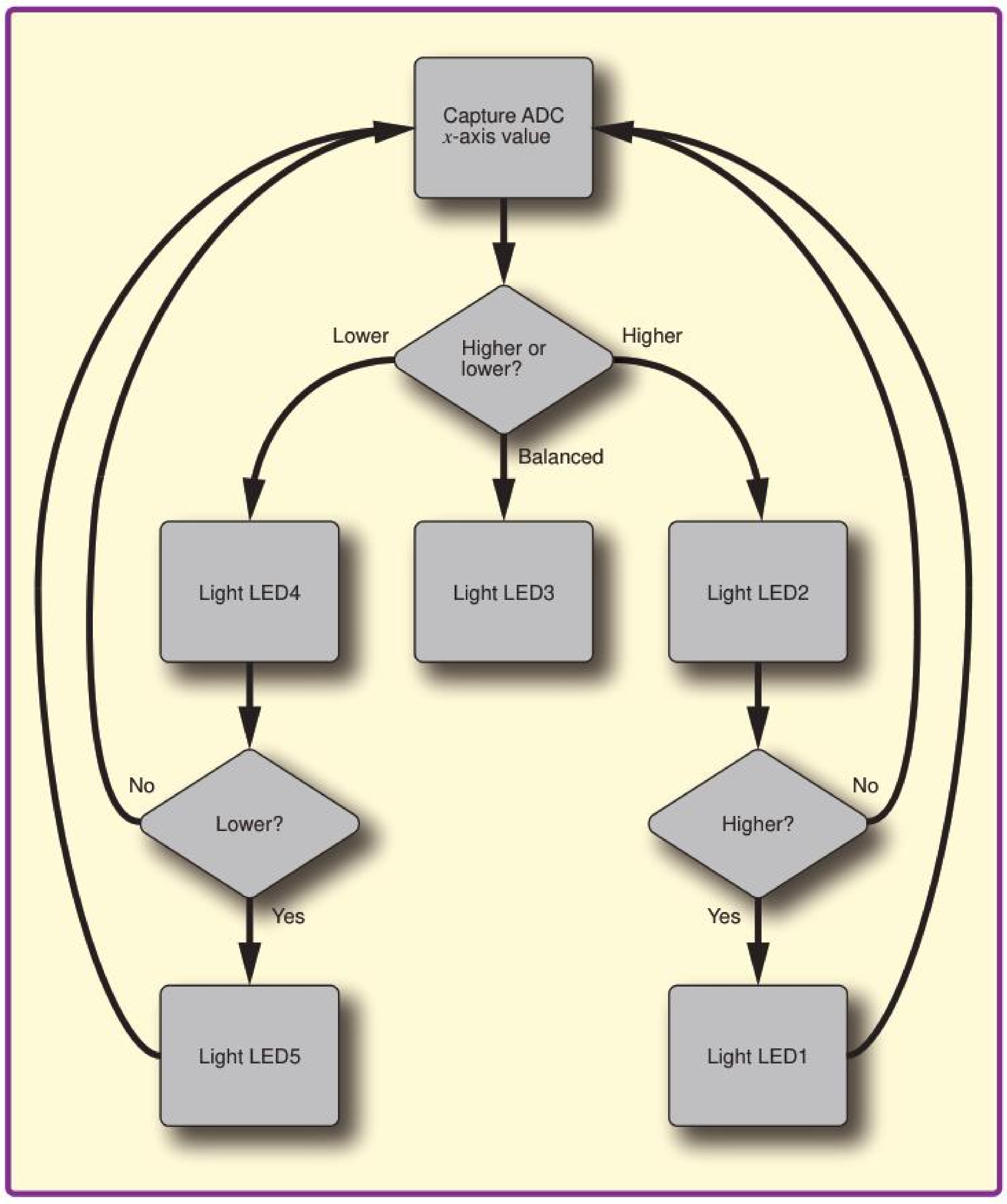
Capture ADC
x-axis value
Lower
Higher or lower?
Higher
Balanced
Light LED4
Light LED3
Light LED2
No
Lower?
Higher?
No
Yes
Yes
Light LED5
Light LED1

Fig.2. Software flow diagram

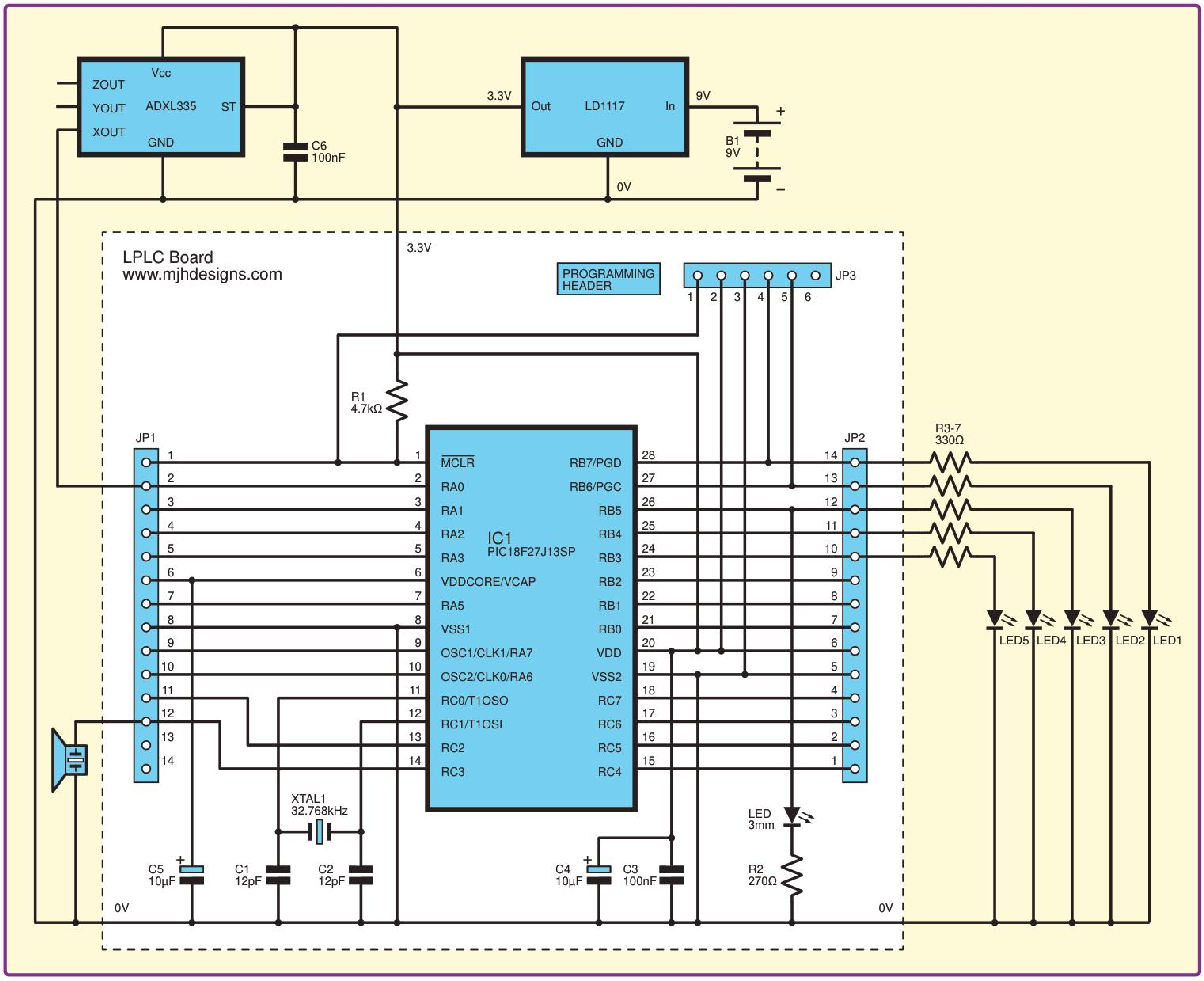
ZOUT
YOUT
XOUT
Vcc
ADXL335
ST
GND
C6
100nF
3.3V
Out
LD1117
In
GND
9V
B1
9V
+
–
0V
LPLC Board
www.mjhdesigns.com
3.3V
PROGRAMMING HEADER
JP3
1 2 3 4 5 6
R1
4.7kΩ
JP1
JP2
R3-7
330Ω
MCLR
RA0
RA1
RA2
RA3
VDDCORE/VCAP
RA5
VSS1
OSC1/CLK1/RA7
OSC2/CLK0/RA6
RC0/T1OSO
RC1/T1OSI
RC2
RC3
IC1
PIC18F27J13SP
RB7/PGD
RB6/PGC
RB5
RB4
RB3
RB2
RB1
RB0
VDD
VSS2
RC7
RC6
RC5
RC4
LED5
LED4
LED3
LED2
LED1
XTAL1
32.768kHz
C5
10µF
C1
12pF
C2
12pF
C4
10µF
C3
100nF
LED
3mm
R2
270Ω
0V
0V

Fig.3. Spirit level circuit diagram

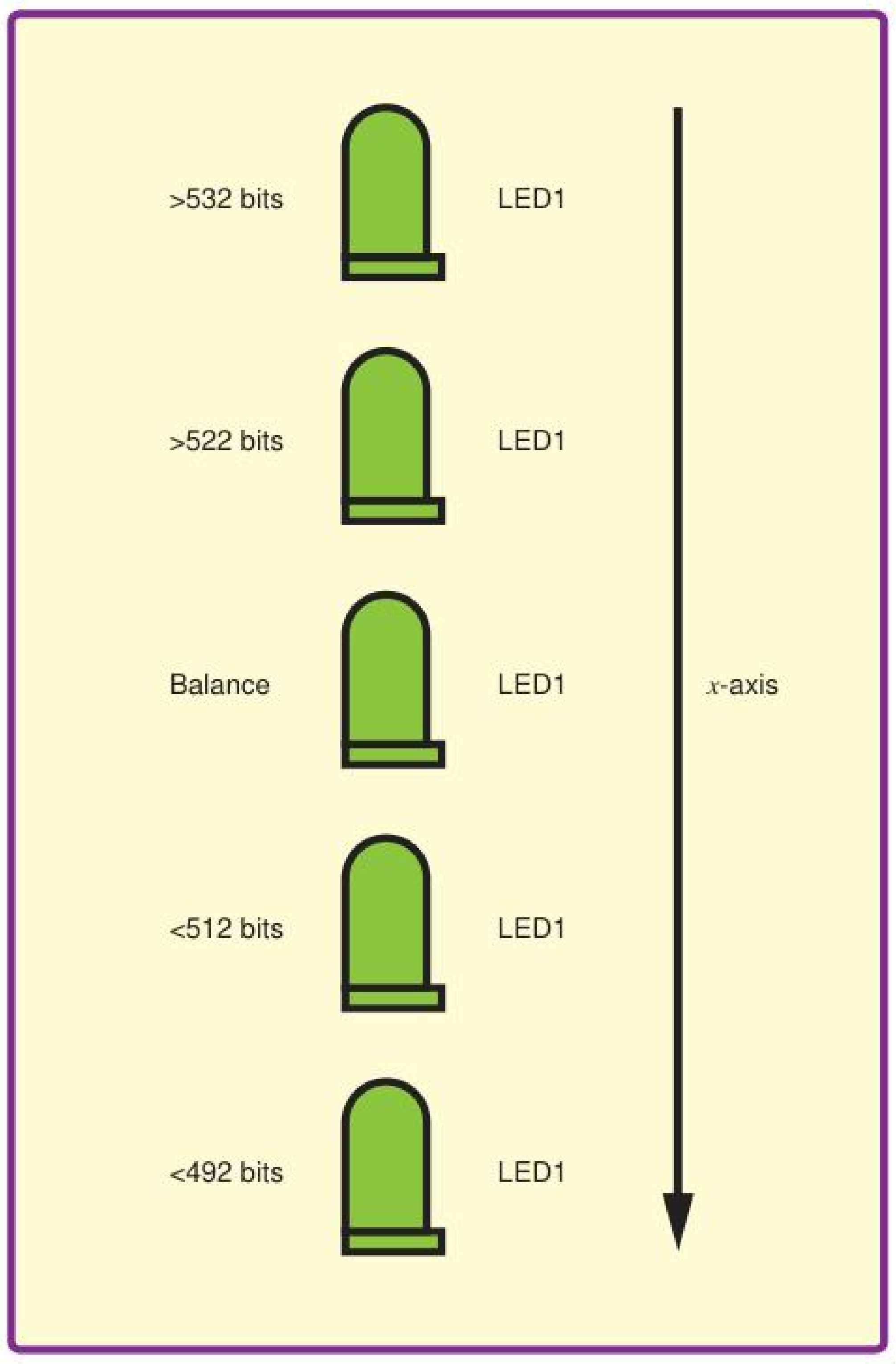

Fig.4. Spirit level indicator LED setup

connected to pins 24 to 28 (PORT B3 to PORT B7) via five 330Ω current-limiting resistors. Choosing middle LED3 as the balance point, LED4 and LED2 are the first-level LEDs and LED5 and LED1 are the second-level LEDs. Fig.4 shows the LED setup.

I've also connected up one side of our electric buzzer to pin 14 (PORT C3) and the other side to ground. Ideally, this buzzer should be driven through a FET, but I wanted to limit the component count. This is a simple circuit to make, but as always check and double-check your connections.

Software

What do we want to do in our software? We want to capture our *x*-axis values through our ADC. If these values are within a certain threshold, then light the appropriate LED.

Now we must define our threshold levels for our LEDs to light. The piece of code shown below (Code 1) means we only have to change the `level_one` variable to adjust our behaviour. This sets our level one threshold and level two threshold values at 10 and 20 bits above and below our 512-bits mid-point value. We define this mid-point as our `balanced_value` variable, equal to 512.

Code 1

```
unsigned int balanced_value = 512;
unsigned int level_one = 10;
unsigned int level_two = (level_one * 2);
unsigned int pos_level_one = 0;
unsigned int pos_level_two = 0;
unsigned int neg_level_one = 0;
unsigned int neg_level_two = 0;
pos_level_one = balanced_value + level_one;
pos_level_two = balanced_value + level_two;
neg_level_one = balanced_value - level_one;
neg_level_two = balanced_value - level_two;
```

Code 3

```
void BuzzerEnable(void) {
        unsigned int i = 0;
        unsigned int toggle_pin = 0;

        for(i = 0; i < 100; i++) {
                delayms(1);
                if(toggle_pin) {
                        LATCbits.LATC3 = 0;
                        toggle_pin = 0;
                } else {
                        LATCbits.LATC3 = 1;
                        toggle_pin = 1;
                }
        }
        LATCbits.LATC3 = 0;
}
```

Now for our main `while` loop. Following our flow diagram, we capture our acceleration value, compare against our `balanced_value (512)` and light our LEDs (or enable the buzzer) accordingly, as shown in Code 2).

The `BuzzerEnable` function is a little more interesting because we need to produce a sinusiodal signal in order to produce a sound. The only simple way to do this is to crudely approximate a sinewave with a square wave and toggle the output pin quick enough and short enough that we can actually hear it, without it being too annoying. The function shown in Code 3 toggles the output 100 times before turning it off. The `delayms` function means it's operating at 1kHz by toggling every 1ms, for 100ms. I found turning it on indefinitely to be irritating. This has a much crisper sound to it. (I could have used a PWM output to control the buzzer, even though this is in effect a 1kHz PWM signal, but done manually by toggling the pin instead of enabling the in-built PWM module in the PIC.)

That is pretty much the guts of the code. Since we're using existing code from a previous project, we don't have to write much more. Code re-use is invaluable and saves time. The remainder of the code is a general setup of timers and the ADC, which was cannibalised from the scope project. You can download the final working code from the *EPE* website under *Library*.

Once we upload our code to our PIC and everything is wired up as in our schematics, we should be ready to go. Our first test should show us that the centre LED is always on and no matter how much we tilt, the other LEDs or buzzer don't turn on. I find this is always the pinch point of any development. I've added in this problem on purpose to try and show how problems arise and how they can be resolved.

Code 2

```
while(1) {
        delayms(250);
        current_adc = ReadADC();

        if(current_adc > pos_level_one) {
                buzzer_enable = 1;
                LATBbits.LATB6 = 1;
                if(current_adc > pos_level_two) {
                        LATBbits.LATB7 = 1;
                } else {
                        LATBbits.LATB7 = 0;
                }
        } else if (current_adc < neg_level_one) {
                buzzer_enable = 1;
                LATBbits.LATB4 = 1;
                if(current_adc < neg_level_two) {
                        LATBbits.LATB3 = 1;
                } else {
                        LATBbits.LATB3 = 0;
                }
        } else {
                buzzer_enable = 0;
                LATBbits.LATB7 = 0;
                LATBbits.LATB6 = 0;
                LATBbits.LATB5 = 1;
                LATBbits.LATB4 = 0;
                LATBbits.LATB3 = 0;
        }

        if(buzzer_enable) {
                BuzzerEnable();
        }
}
```

My initial guess would be that our threshold levels are too high. Let's change it right down to 1 instead, swapping this line in for our line mentioned above.

```
unsigned int level_one = 1;
```

The rest of the code will adjust to this value. Having compiled and programmed our board again, we should now see our board fully functioning and lighting the LEDs and sounding the buzzer as we tilt it.

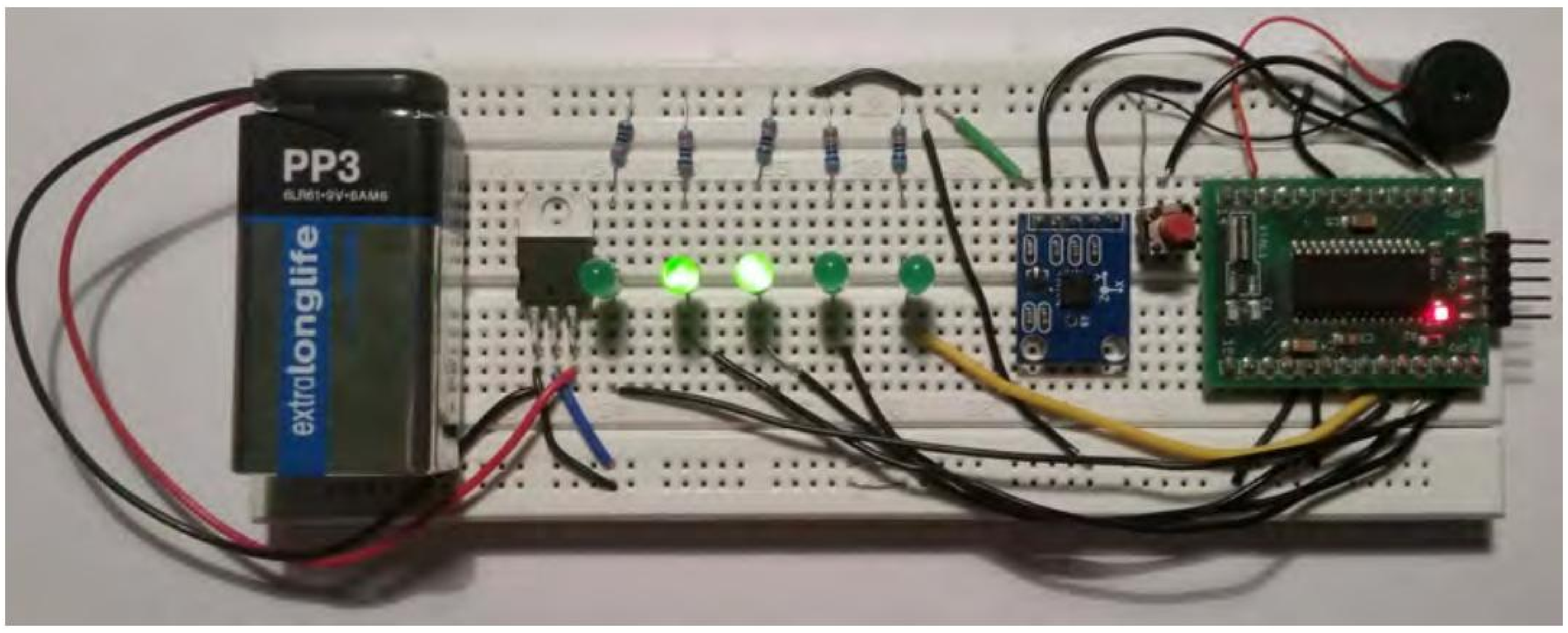

Fig.5. Final working board of the accelerometer-based spirit level

Conclusion

Fig.5 shows our working finished project. As you can see from the photo, the LED to the left of the centre LED is lit, showing that my desk is not as level as I thought it was. I decided to compare it against a traditional spirit level bought from B&Q and I found my new digital project to be far more accurate.

This is just the start of what could be a fascinating project. You could easily increase the accuracy and sensitivity with extra LEDs. Why not make the LEDs nearest to the centre point have a lower threshold spacing so that as you approach the horizontal you can really fine tune finding the horizontal. Since we have a three-axis accelerometer, a nice add-on function would be to have another set of LEDs in the *y*-axis, making a cross, so that you could measure the orientation of a plane, not just a line. Maybe you could build a 5 × 5 × 5 LED cube, which lights the LEDs based on its rotation and angle. Taking this to the next level, you could build a one-two or three-axis angle meter. Let me know how you get on and share it online at *Chat Zone*.

Next month

This month's project turned out well and I'm very happy with it. With the latest *Teach-In* series on Arduinos, I think next month would be a great time to go back to the basics of PIC development using the PICkit 3, Low Pin Count Demo Board and maybe in a few months look at the Curiosity Development Board alongside Microchip's brand-new MPLAB Xpress Cloud-Based IDE (see this month's *News*). This will be ideal for those of you who are new to the world of PICs or if you want to improve your basic understanding.

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at @MikePOKeeffe, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

HP 34401A Digital
Multimeter 6 ½ Digit

HP 54600B Oscilloscope Analogue/Digital
Dual Trace 100MHZ

MARCONI 2955B Radio
Communications Test Set

FLUKE/PHILIPS PM3092 Oscilloscope
2+2 Channel 200MHZ Delay TB, Autoset etc

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CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

Oversampling with ADCs

REGULAR *EPE Chat Zone* contributor ***atferrari*** started a thread relating to a project in which he is using oversampling with the 10-bit analogue-to-digital converter (ADC) on a PIC18F4431 (**www.microchip.com**). He is aiming to achieve an effective resolution of 12 bits. A day or so later he fixed the problem which triggered the original post; however, another regular contributor, ***james***, expressed interest in learning more about oversampling – particularly the seemingly counterintuitive fact that noise may have to be added to the signal to improve the effective ADC resolution. This is an interesting technique, and one that is of potential interest to anyone who develops their own microcontroller systems.

ADCs built into PICs and other microcontrollers are very useful and help keep component counts low, but sometimes they do not have the required capabilities. Usually, this requires use of an external ADC, typically connected to the microcontroller via a standard serial bus such as SPI or I^{2}C. If the issue with the built-in ADC is that the resolution (number of bits) is insufficient then oversampling may be a solution, particularly for relatively low frequency signals. However, oversampling in general is not limited to the internal ADCs of microcontrollers and very slow signals – it can be used on a wide range of ADCs in a variety of contexts.

Before discussing oversampling we will explain some basics of ADCs, particularly in relation to sampling requirements – we need to define what 'normal' sampling is for the term oversampling to be meaningful. Since we are interested in the effect of oversampling on resolution we also need to discuss ADC resolution and look at the implications of different resolutions.

Codes

An ADC takes an input voltage and outputs a digital code representing that voltage. Two reference voltages in the ADC circuit set the range of input voltages over which an ADC performs valid conversions: the low reference voltage (V_{RefL}) and the high reference voltage (V_{RefH}). One reference point can be (and often is) ground, but it does not have to be. For accurate and consistent conversion these reference voltages must be properly set and maintained (voltage references were discussed in detail in the previous two *Circuit Surgery* articles). The quality of the converted data depends not only on the quality of reference, but also (of course) on the performance of the ADCs itself, signal processing prior to the ADC and subsequent data processing.

When an analogue signal is converted for digital processing by an ADC the resulting digital representation has a finite number of possible levels (codes), rather than the effectively infinite number of possible analogue voltages (or currents). This is illustrated in Fig.1, which shows the input-output relationship (transfer characteristic) for four data converters. In all cases the input is an analogue voltage and the output is a digital code.

Fig.1(a) and Fig.1(b) are both 3-bit converters, but they differ in the voltages at which code transitions occur. Fig.3(b) is referred to as a ½-LSB-compensated transfer characteristic, in which the first code transition occurs at half the voltage of the uncompensated converter. We will define 'LSB' more formally shortly. Fig.1(c) shows a 4-bit converter transfer characteristic and Fig.1(d) an idealised (and fictional) converter with an infinite number of bits. This idealised characteristic is important because it acts a reference point for determining errors of ADCs with realistic numbers of bits and real-world imperfections.

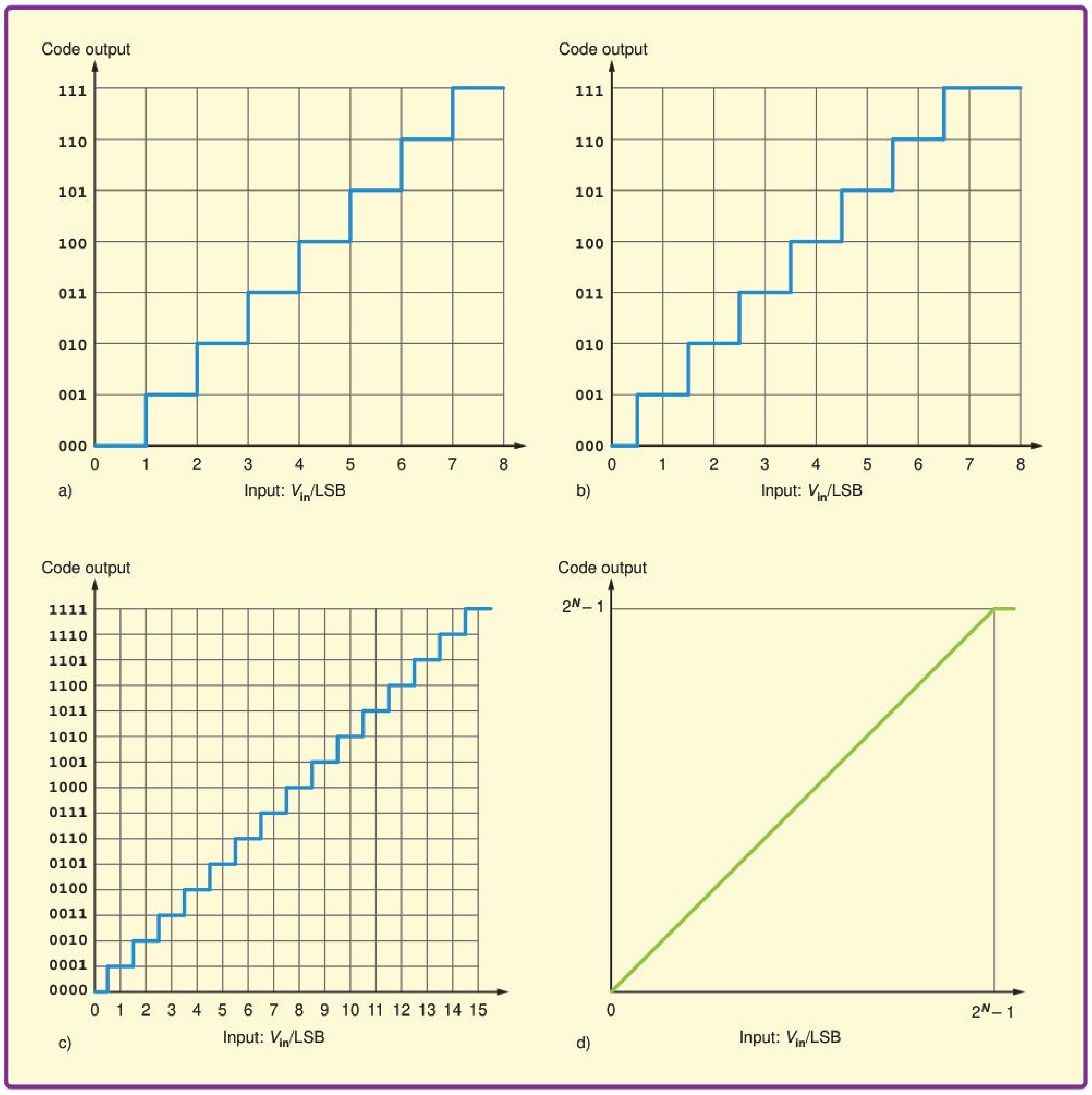

Fig.1. Input-output (transfer) function for ADCs: a) uncompensated 3-bit ADC (8 output codes), b) ½-LSB-compensated 3-bit ADC, c) 4-bit ADC (16 output codes), d) ADC with an infinite number of bits, N *– this is the ideal 'straight line' transfer function*

LSB

An ADC transfer characteristic has a staircase shape. The more bits in the output code the more steps we get in the complete transfer characteristic, as can be seen by comparing the 3 and 4-bit characteristics in Fig.1b and Fig.1c. ADCs often have many more than 3 or 4 bits, so a plotted transfer characteristic for, say 16-bits, will look much like a straight line, but it will still have a staircase structure (if you zoom in). With an infinite number of bits the transfer characteristic would be a perfect straight line, as seen in Fig.1d.

An *N*-bit ADC converts analogue input data into 2^N codes. The voltage difference between adjacent codes is called the least-significant bit (LSB). LSB is given by:

$$LSB \approx \frac{(V_{\mathrm{RefH}} - V_{\mathrm{RefL}})}{2^N}$$

For example, if a 12-bit ADC has $V_{\mathrm{RefL}} = 0$ and $V_{\mathrm{RefH}} = 5\mathrm{V}$ the LSB is:

$$LSB = \frac{5}{2^{12}} = \frac{5}{4096} = 1.22mV$$

The maximum code (ideal straight line characteristic) is output for a voltage of one LSB less than the upper reference voltage. This is called the full-scale (FS) voltage.

Due to the finite number of codes the voltage represented by the ADC's code after conversion will not generally be exactly equal to the original input voltage. The difference is known as the 'quantisation error'. This error has a maximum value of ±½LSB with a ½LSB compensated transfer function. For a non-compensated converter the maximum error is 1 LSB. In both cases the range between the two extremes of the error value is 1 LSB. The variation of quantisation error with input voltage for a 3-bit, ½-LSB-compensated ADC is shown in Fig.2.

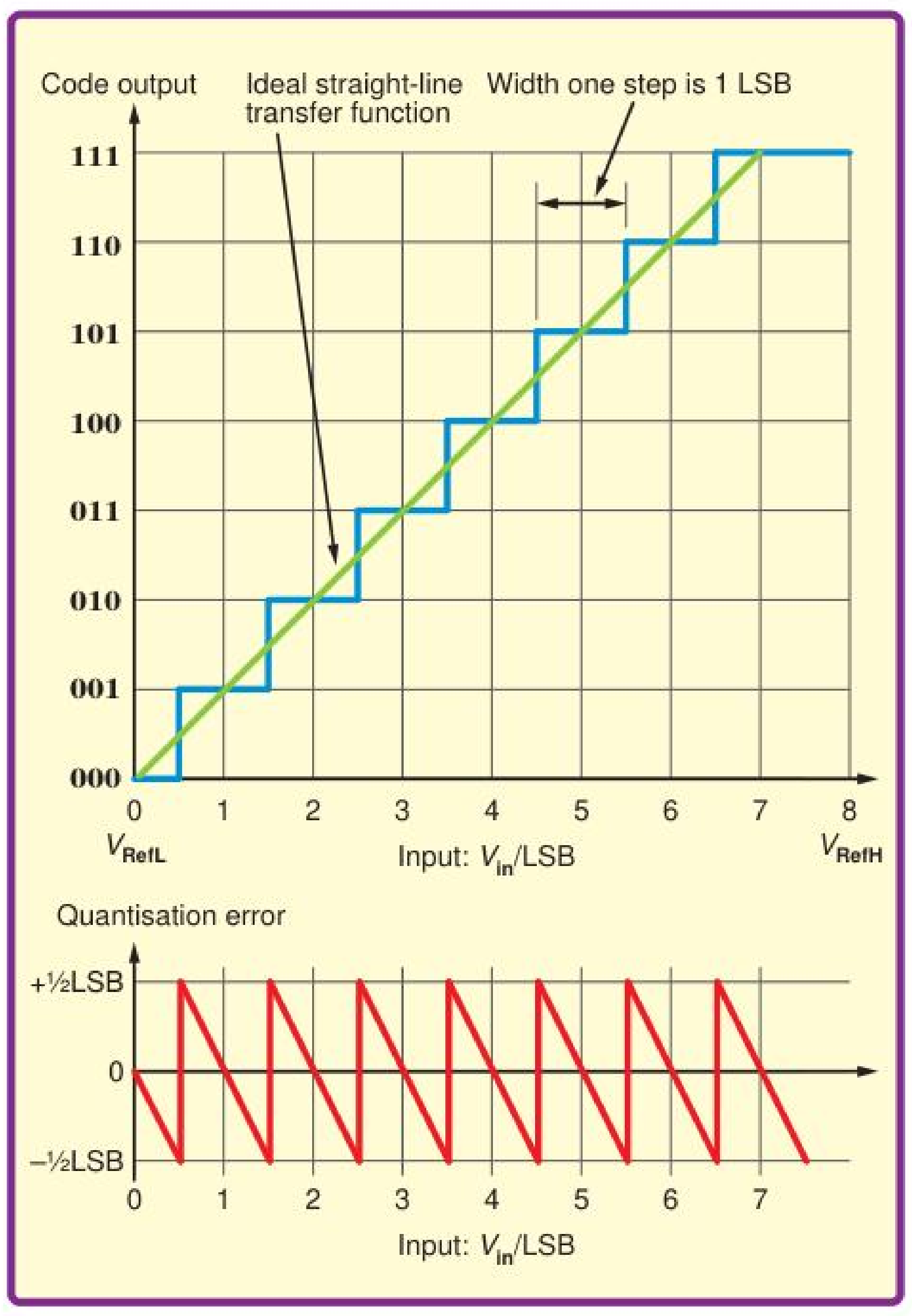

Fig.2. Comparison between the ideal straight-line transfer function and the actual transfer function of a perfect ½-LSB-compensated 3-bit ADC. The difference is the quantisation error

Table 1: Information on ideal ADCs with a variety of number of bits (ppm: parts per million)

Number of bits	Number of codes	Relative size of LSB	SNR in dB	LSB voltage for 5V input range
3	8	13%	–20	625mV
4	16	6.3%	–26	313mV
8	256	0.39%	–50	19.5mV
10	1024	980 ppm	–62	4.88mV
12	4096	240 ppm	–74	1.22mV
16	65536	14 ppm	–98	76.3µV
22	4194304	0.24 ppm	–134	1.19µV
24	16777216	0.060 ppm	–146	0.298µV

Quantisation error is not the result of non-ideal circuit components; it is a fundamental property of the conversion process. An ideal 3-bit ADC produces the quantisation errors shown in Fig.2. Real ADCs will produce additional errors due to imperfections in their circuitry.

Signal-to-nose ratio

If an ideal ADC is used to measure the same fixed voltage in a noise-free circuit the same quantisation error will occur each time. However, if an ADC is used to sample a continuously varying signal (eg, audio) then the quantisation errors will be different on each conversion and over time they will have the same statistical properties as random errors. Thus quantisation adds noise to a digital representation of a signal that was not present in the original analogue input. For *N*-bit quantisation of a sinewave spanning the ADCs full input range the signal-to-noise ratio (SNR) due to quantisation is given by:

$$\mathrm{SNR} = 6.02N + 1.76\ \mathrm{dB}$$

Adding an extra 1 bit of resolution provides about 6dB improvement in the SNR. Again, this is for an ideal converter; real converters will add additional noise. Oversampling has the potential of improving the SNR of a converter by reducing the quantisation error.

We can rearrange this equation to find *N* and use it for any circuit to determine the effective number of bits (ENOB) for that circuit. For ENOB we used SINAD (signal to noise and distortion), the ratio of noise plus distortion to signal, rather than signal-to-noise ratio (SNR) so that all non-ideal aspects of the circuit are covered. ENOB indicates the number of bits in an ideal ADC that would have the same resolution as the circuit under consideration. Real ADCs may have ENOBs lower than the actual number of bits.

$$ENOB = \frac{SINAD - 1.76\mathrm{dB}}{6.02}$$

Thinking about the size of an LSB and the ENOB of the ADC and other parts of the circuit is useful when designing a system containing ADCs. Table 1 helps provide an idea of LSB and resolution of ideal ADCs expressed in a number of ways – as the number of codes, as the LSB as a percentage or parts per million of full input range, the SNR of the quantisation noise and the LSB voltage with a 5V range.

Sampling

The preceding discussion has focused on the voltage resolution of ADCs; however, we also need to consider what is effectively the time resolution of the ADC, that is, how often the ADC performs a conversion. This is referred to as the 'sampling rate', and is measured in samples per second, or commonly kilo- and mega-samples per second (ksps, Msps).

Aliasing is a problem that can potentially occur in any signal processing system that samples a signal. This includes all digital audio and video signal processing. It also includes analogue sampled signal circuits such as switched-capacitor filters. Digital imaging devices such as cameras and scanners can also suffer from aliasing effects. Aliasing is so called because it causes ambiguities in the sampled data, that is, there could be more that one signal which resulted in the same set of sample values – thus one signal is an 'alias' of the other.

Wagon wheels

Aliasing effects can be observed in everyday life; one often-quoted example is the 'wagon wheel effect', where the wheels of a vehicle in a film or video (perhaps a stagecoach in a western, as the name suggests) appears to be turning at the wrong speed, backwards or even stationary. Search the web for 'wagon wheel effect' videos if you would like to see some examples.

A video camera samples the scene in front of it at a certain number of

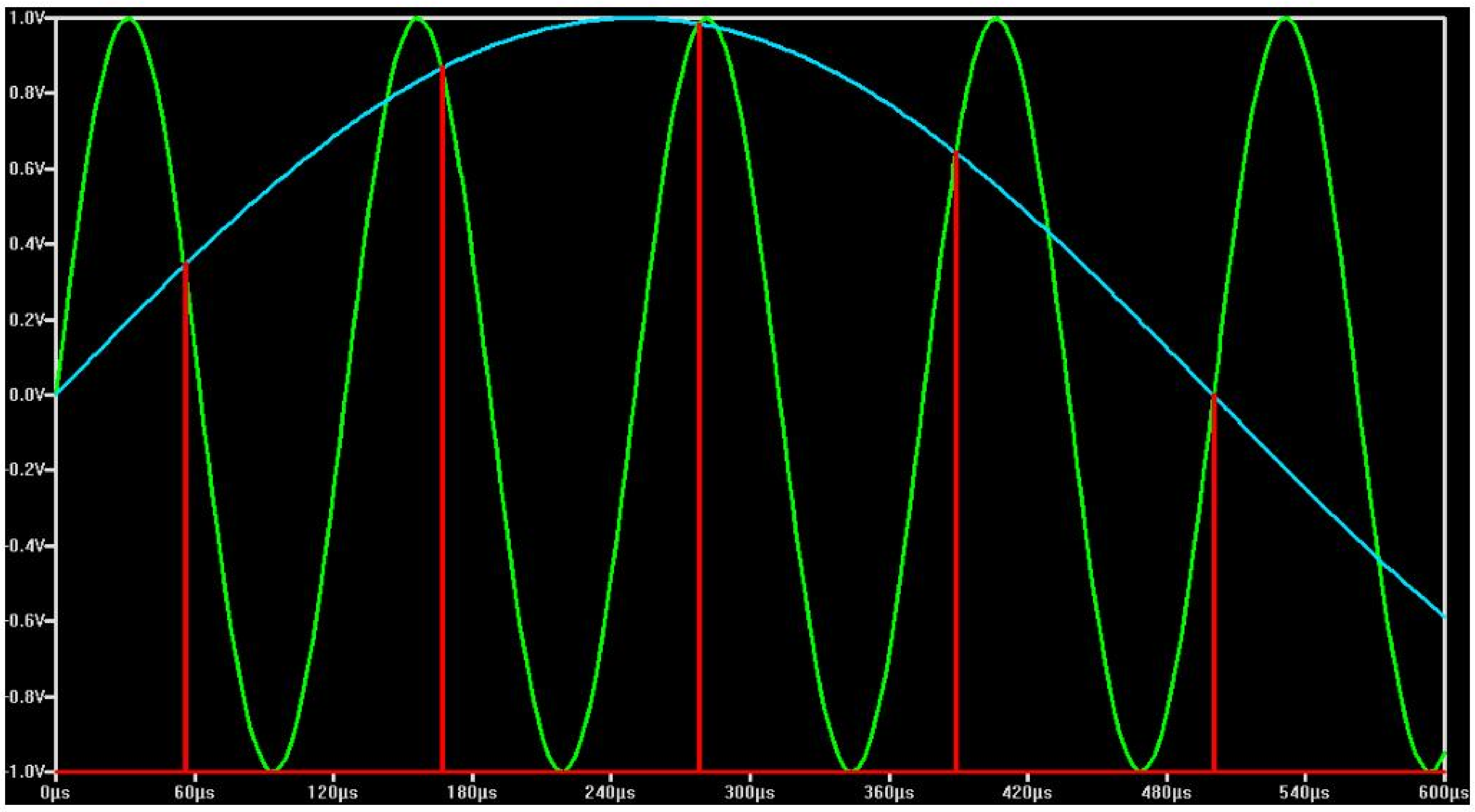

Fig.3. Aliasing of sampled signals – the green and blue waveforms both produce the same set of samples from the red sampling waveform and are therefore indistinguishable after sampling

frames per second. If the wheel of a vehicle in the shot rotates an exact number of whole revolutions in the time between frames it will appear to be in the same position in each frame. When the film is viewed the wheel will appear to be stationary, despite the fact that the vehicle is obviously in motion. However, if the wheel was rotating much more slowly, or if the video frame rate was much higher, we would get a large number of frames per revolution and playback would look as it should. This leads us to the insight that problems will occur if the input (the scene in this case) contains frequencies relatively close to the sampling frequency.

Aliasing of waveform sampling can be seen in Fig.3. Here we have two sine waves at frequencies of 1kHz and 8kHz, with a sampling process running at 9kHz. The sampling process is indicated by the red pulses in the figure. The sampling signal obtains the same signal values from both of the sine waves. Thus, if we only have the sample data (further through the signal processing system, or in a digital recording), we cannot tell if the data was due to a 1kHz or 8kHz sinewave.

Nyquist

Another way to look at this is that if we sampled an 8kHz sine wave at 9kHz then when the signal was reconstructed (eg, when playing a digital audio recording) we may end up with a 1kHz tone instead of the original 9kHz. The output contains something that was never there in the first place – just like the illusionary stationary or backward-turning wheels on the 'wagon'. Mathematical analysis of the process of sampling a signal shows the signals with a frequency of less than half the sampling frequency are reliably represented in the sampled data. This is known as the Nyquist–Shannon sampling theorem. The theory shows that if the input does not contain any frequency components beyond half the sampling frequency then it is possible to perfectly reproduce the original signal from the sample data.

A sampling frequency of twice the maximum signal frequency is called the 'Nyquist frequency' or 'Nyquist rate'. Sampling at less than this frequency is called 'undersampling' (which does have its uses). Sampling a rate significantly higher than the Nyquist rate is called 'oversampling'.

Oversampling

There are a few reasons why oversampling might be used. First, in order to meet the requirements of Nyquist–Shannon sampling a low-pass filter is often needed to remove alias-causing higher frequencies from the input signal. This is known as an anti-aliasing filter. The closer the sampling frequency is to being twice the maximum wanted input frequency the more demanding the job of the anti-aliasing (it needs a sharper cut-off). Oversampling can lead to a more relaxed anti-aliasing filter requirement, which may be easier to design, or cheaper, or both.

Oversampling can also be used to improve the effective resolution (ENOB) of an ADC, with suitable processing of the sampled data. There are ADC circuit designs that are inherently oversampling; these are called oversampling converters, noise-shaping converters or delta-sigma (or sigma-delta) modulators (ΣΔ modulator). ΣΔ modulators require less demanding analogue circuits but more digital processing than other converters. Non-inherently oversampling converters are sometimes called Nyquist ADCs to distinguish them from ΣΔ modulators.

Nyquist ADCs can be used to oversample a signal in situations where their sample rate can be significantly higher than twice the maximum frequency of their input signal (after appropriate filtering is applied). Doing this is less effective at improving ADC performance by oversampling than the full ΣΔ modulator approach, but can be used with any converter where there is spare sampling speed capacity (ie, it is capable of sampling faster than is actually needed for the task in hand). This is the scenario discussed by ***atferrari*** and ***james*** on the *EPE Chat Zone*.

Resolution

To increase the resolution of a converter by n-bits by oversampling the oversampling frequency, f_S, is selected with respect to the Nyquist frequency, f_N, as follows

$$f_S = 4^n f_N$$

For example, to get 12-bits effective resolution from a 10-bit converter we have $n = 2$ and need a sampling frequency of $4^2 = 16$ times the Nyquist frequency. The oversampled data at the converter's native resolution is used to produce a set of higher resolution samples at the Nyquist frequency. The process of producing the slower rate, higher-resolution, data from the faster, lower resolution data is called 'decimation'; it is a form of low-pass filtering. Decimation is the opposite of interpolation, where additional data points are calculated in between those actually measured.

For the resolution improvement to work, some conditions must be met. First, the signal being sampled must remain constant to within the effective LSB of the enhanced resolution while sufficient samples are taken to obtain the higher resolution value. This applies just to the signal itself and very specifically not to the random noise on top of the signal. Also, the converter has to be linear to the higher resolution. For ordinary conversion all the switching points between codes must be accurately placed with respect to the ideal straight-line characteristic (eg, the converter shown in Fig.2 is perfectly linear). If the effective resolution is to be increased the linearity must match the improved resolution (a more accurate switching point requirement).

Noise

Another requirement, as mentioned earlier, is that the sampled signal must have noise present which is a least 1 LSB in amplitude. To understand this we need to look at the properties of a noisy signal and the response of an ADC to it.

If we make instantaneous measurements, using a perfect measurement instrument, of a signal which is constant during the measurements, but which is subject to random noise, then each measurement will be slightly different due to the noise. If we make a very large number of measurements we will be able to take the average and obtain a more accurate value for the signal than is likely from making a single measurement. We

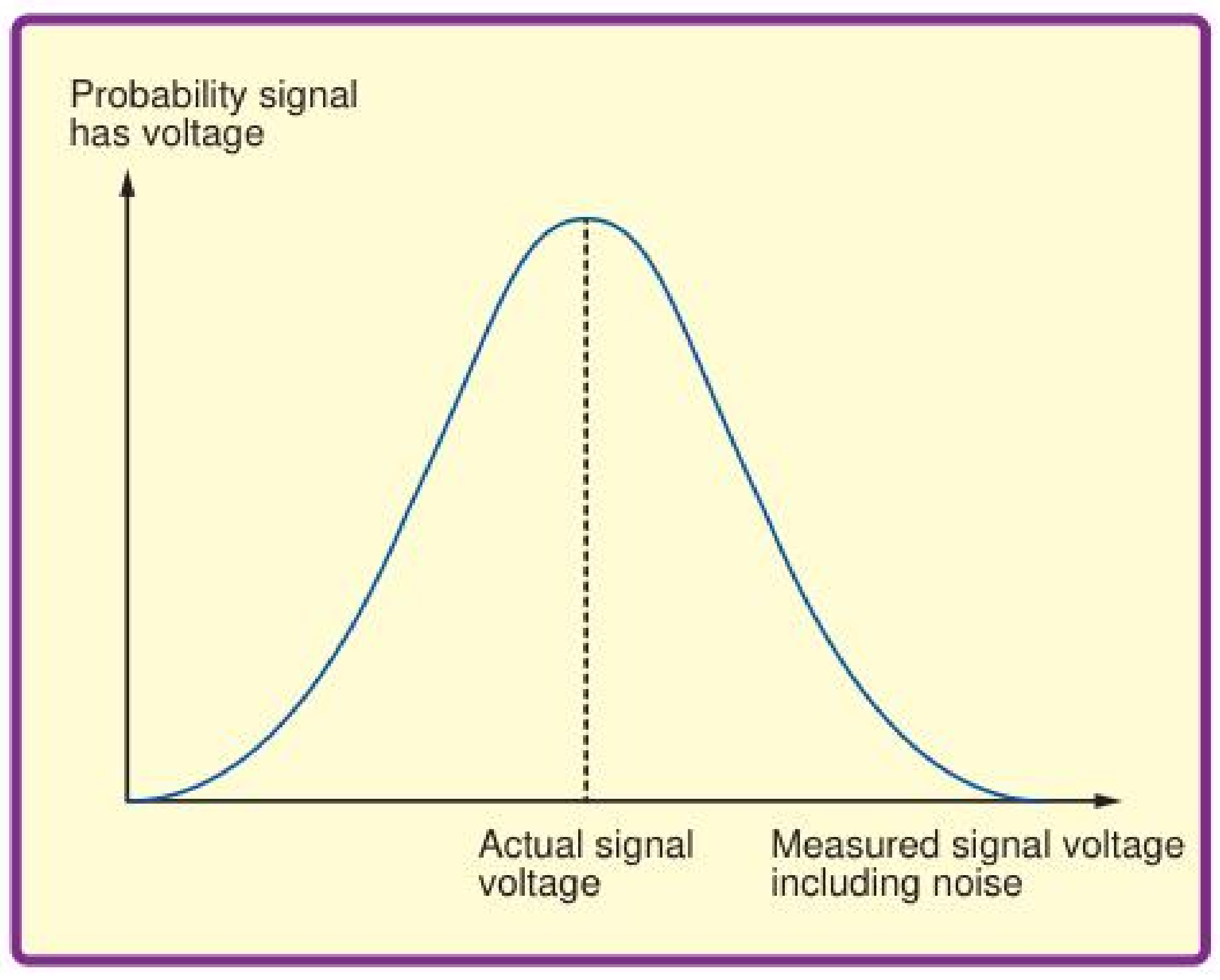

Fig.4. Probability that that a fixed signal voltage plus noise has a particular measured voltage

will also be able to look at all the data and find the probability that a single measurement takes a particular value. Typically, for truly random electronic noise this probability relationship will be the well know Gaussian or normal distribution (see Fig.4) with the true signal value corresponding to the peak of the curve (the mean).

Consider a constant, but noisy, signal applied to an ADC. Assume the signal has a value exactly halfway between two ADC code-switching points, and assume the noise amplitude is around 2 or 3 LSBs. Each conversion results in one of several codes; depending on the noise at the instant the signal was converted. If we make several conversions and count the number of times we obtained each code, we will be able to plot a histogram showing how often each code occurred (see Fig.5). As our signal is exactly centred on one code, the likelihood of obtaining codes 1 LSB above and below will be equal (similarly with codes 2 LSB above and below etc.). The histogram of codes will be symmetrical.

Now consider a very similar scenario, but with the actual signal voltage somewhere other than exactly halfway between two codes. Let's assume the signal is above halfway between the two code switching points, as shown in Fig.6. Here the statistics of the noise will cause the code 1 LSB above the actual signal code to occur more often than the one 1 LSB below, and similarly with codes further removed from the actual signal code. The histogram of codes measured will be non-symmetrical as shown in Fig.6.

Processing

We can process the measured codes in the scenarios in Fig.5 and 6 to obtain a more accurate reading. If we manually average all the code values in the histograms (eg, using a calculator with full-precision real-number calculation). We will get exactly the 'centre' integer code value for the data in Fig.5. For the data in Fig.6 we will get a value of about 'centre code value' +0.25, reflecting the fact that (in this case) the signal is about a quarter of the way towards the centre of next code range compared to that in Fig.5. Thus the data has the potential to indicate where the signal is *between* codes and therefore to increase the resolution. However, we need to consider how the data will be processed in digital hardware or microcontroller code where we will usually use integer data with a fixed number of bits.

In digital processing a standard averaging low-pass filter would take 10-bit data in and produce 10-bit data out at the same rate; this not what we need for resolution increase because we have not increased the number of bits. We need to decimate the data by a factor of f_S/f_N – that is, the reciprocal of the oversampling ratio and produce 'averaged' date that has the required extra bits.

The simplest approach is to take batches of 4^n samples and add these all up, which will require $2n$ more bits than the ADC to hold the result (14 bits in the case of $n = 2$, with a 10-bit ADC oversamples at ×16). The result is shifted right by n bits, throwing away the least significant n bits and producing the final improved resolution result, which will have n bits more than the ADC. Each batch of 4^n input samples produces one result, so the original oversampled data has been downsampled (decimated) by a factor of 4^n back to the Nyquist rate.

Dithering

What happens if the noise amplitude is low, specifically if it is smaller (or much smaller) than one LSB? This is illustrated in Fig.7. In this case the signal value is about halfway between the two code switching points and the noise illustrated will never (or only extremely rarely) cause the ADC output code to change. We

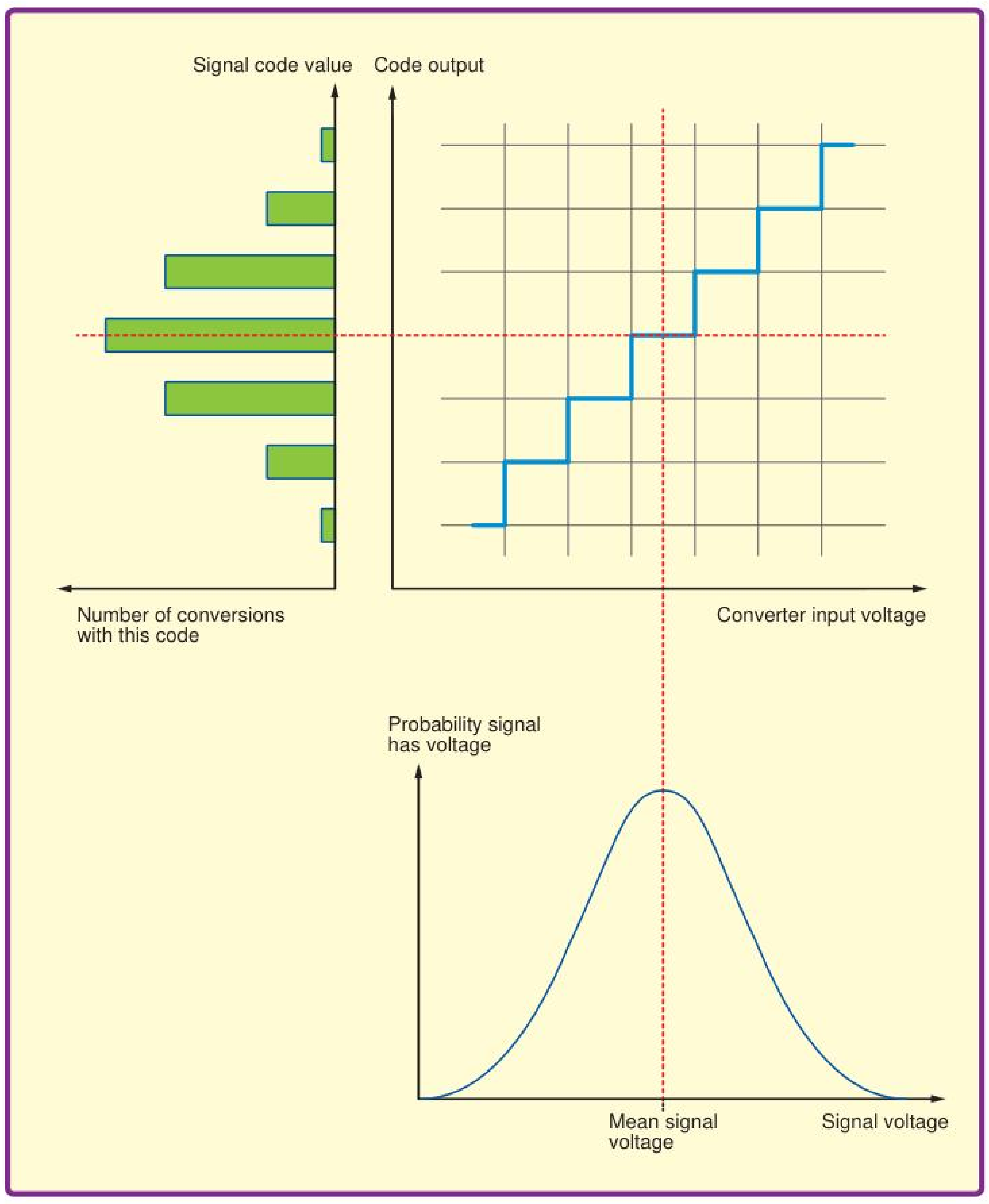

Fig.5. Effect of applying a fixed signal plus noise with an amplitude of a few LSBs to an ADC where the fixed signal is exactly midway between two code transitions. Note symetrical histogram of code counts

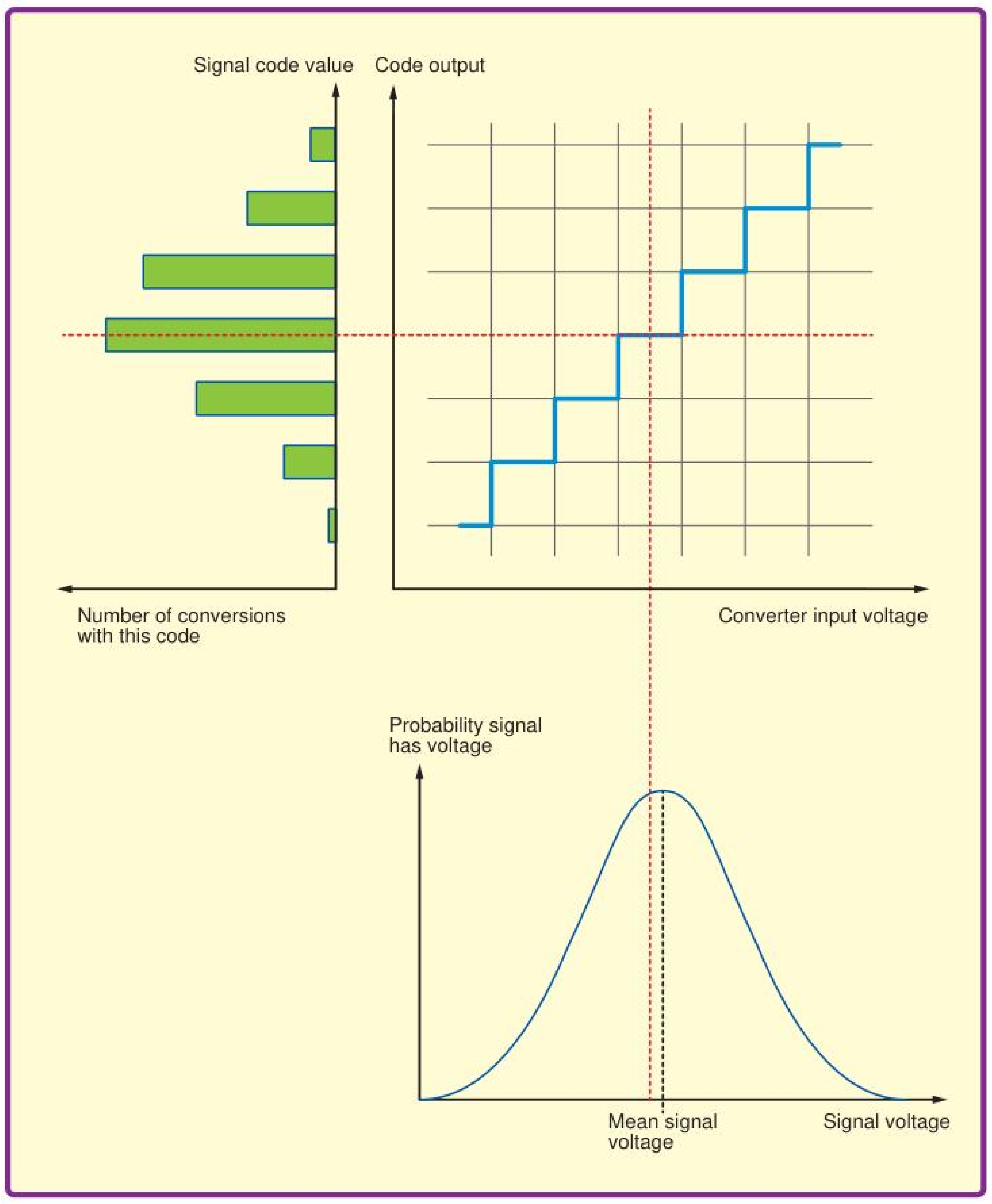

Fig.6. Effect of applying a fixed signal plus noise with an amplitude of a few LSBs to an ADC where the fixed signal is closer to one code transition than another. Note the asymetrical histogram of code counts

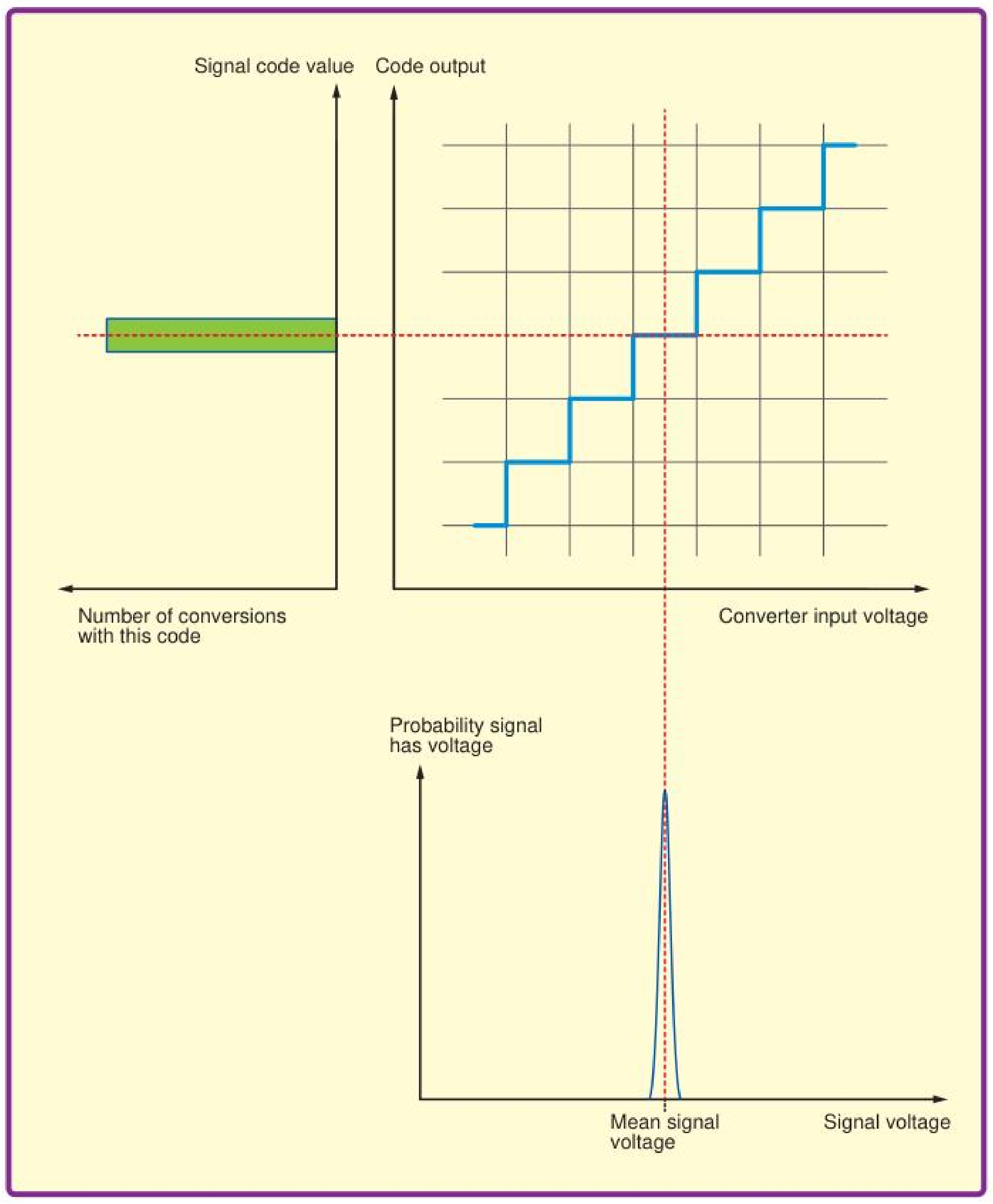

Fig.7. Effect of applying a fixed signal, plus noise with an amplitude of less than one LSB, to an ADC. Note that all conversions produce the same code

do not get a histogram, just the same value every time, so we cannot process multiple samples to get a more accurate value. If the low-noise signal was very close to a code switching point we would get two possible values, but for most inputs the situation depicted in Fig.7 would prevail.

This shows that the input must contain noise for this approach to work. It does not matter how large the noise signal is, as long as it is truly random and of sufficient amplitude to cause codes close to the mean to occur as we make multiple samples. If the noise is not truly random (eg, correlated with other signals in the system) the obtained codes may be biased in one direction or another.

In many cases in real circuits, with converters having a reasonable number of bits, the naturally occurring noise in the circuit is sufficient to meet the 1 LSB+ condition. If it is not, then we have to add noise to the signal, a process known as dithering. The noise can be generated using analogue or digital techniques, depending on what is most convenient for the system. Analogue noise generators typically amplify the ac part of the signal from a Zener diode or transistor base-emitter junction reverse biased into breakdown. Noise can also be generated digitally using a linear feedback shift register circuit. Noise can be added to the signal using an op-amp summing amplifier circuit.

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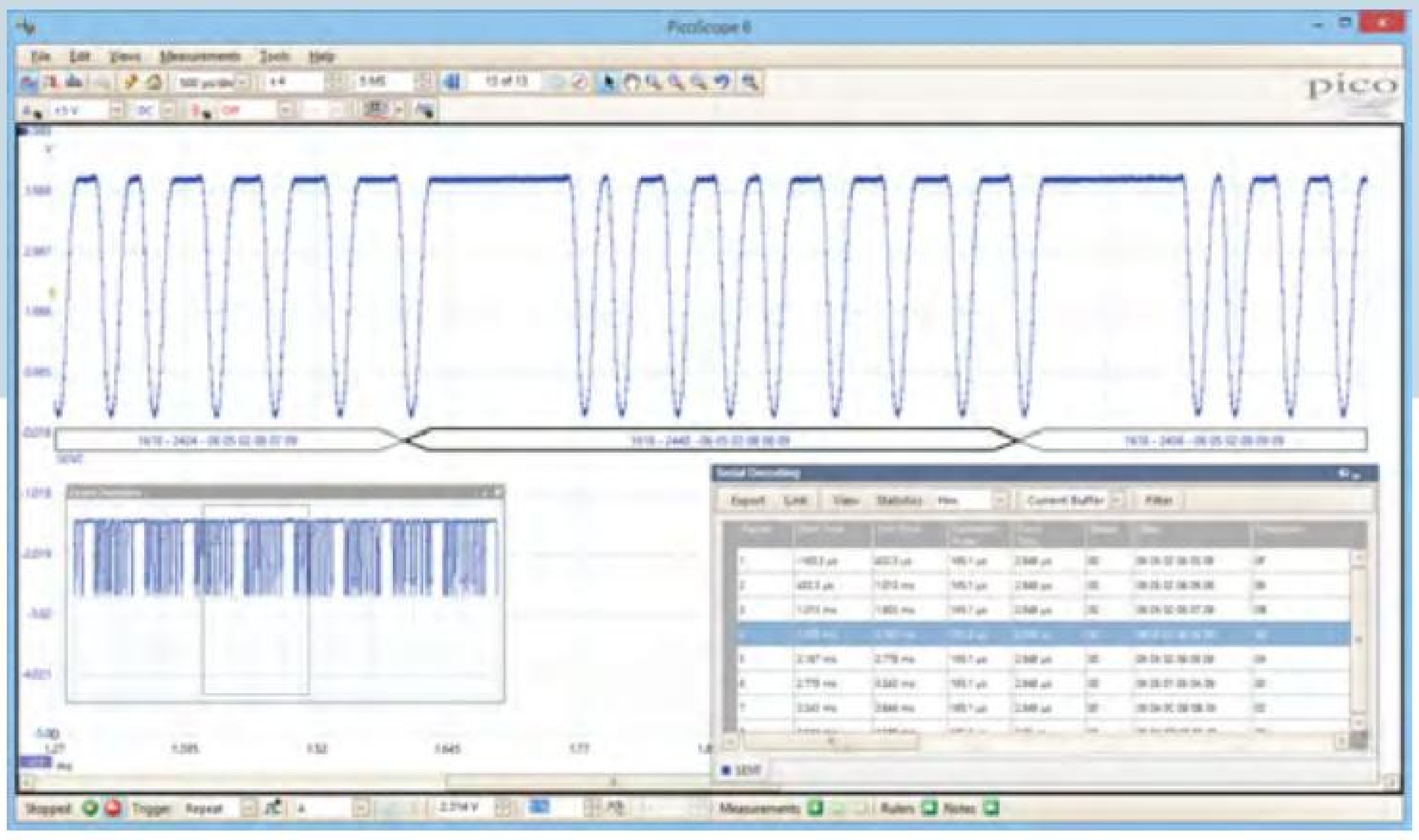

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READOUT

Matt Pulzer addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!

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All letters quoted here have previously been replied to directly

Email: editorial@wimborne.co.uk

✫ LETTER OF THE MONTH ✫

Controlling Windows updates

Dear editor
I was very much in sympathy with Alan Winstanley's comments on Microsoft's tricks to get people to update from W7/8.1 to W10 in March's *Net Work* column.

I for one intend to stick with W7 until my computer dies, mainly because I have had bad experiences with hardware drivers not working after previous 'upgrades' rendering perfectly functional hardware obsolete.

To this end I use a GWX Control Panel from: **http://blog.ultimateoutsider.com** to prevent further encroachment by GWX; see: **http://tinyurl.com/pzzpkn8**

Eventually computers die and we will all have to go to W10. As you identify, a most objectionable feature of W10 is the forced (buggy) updates. To try and change this, there is a petition to persuade Microsoft to modify this policy on **www.change.org**, see: **http://tinyurl.com/zxsflv4**

Your readers might be interested in visiting these sites and installing and/or voting. I have had GWX Control Panel for some time and can confirm it is a well-behaved piece of software, which does what it says on the label, and can be reversed if required.

David Shore, by email

Alan Winstanley replies:
Thanks for writing to EPE*; I have heard of the GWX control panel but (at that time anyway) I wasn't sure whether it still worked or whether Microsoft had done some workaround or other. I will take another look. At present, I have found that uninstalling and hiding the various Windows so-called 'updates' seems to have done the trick, but I still have to keep an eye on things.*

I too intend to run my W7 PC into the ground, as the W10 upgrade would also force me into subscribing to Adobe Creative Suite, at the not very sweet price of £27 to £45 a month for ever more. Being forced into subscribing to software this way goes against my Yorkshire roots!

DIY PCBs

Dear editor
I have ordered PCBs for the *2.5GHz Frequency Counter* (*EPE*, February 2014) but I would like to have a go at making my own. Can you help with artwork?

Paul Taylor, via email

Alan Winstanley replies:
Without the original artwork or gerber files, I'm afraid it's not possible any longer to produce these boards at home. We used to offer 1:1 'camera ready' artwork in older projects and readers would scan them from the page or use 'Press & Peel' to make their own etch resist pattern. Since 2006 the projects mostly originate from Silicon Chip *and the designers may retain commercial copyright in the board design. We are faced with a choice of publishing designs that way or depriving readers of projects and not publishing anything at all.*

The only solution would be to capture the schematic using PCB CAD software and recreate the design yourself, which is probably not practical.

I'm sorry if this isn't the answer you hoped for. A few more details are available in our Library Help pages at: **www.epemag.com/library-help.html**.

We published an up-to-date series on making your own PCBs, starting in the September 2014 issue, using modern software – see: **www.epe-magazine.co.uk/proj/0914.html**

Also, subscribers can obtain digital artwork for later projects (where it's available) free of charge, otherwise it's still possible to purchase digital artwork from us for a nominal sum. It is normally a PDF file. Please contact us at: **enquiries@wimborne.co.uk**

It would still be necessary to process it manually on a PC in order to output etch resist artwork on film that you can then UV-expose onto UV sensitive board in the traditional way. Alternatively, some choose to 'iron it on' to a copper clad PCB using Press & Peel transfer film. This is a hit-and-miss affair to begin with, so it would be necessary to experiment, but usually it yields perfectly good results once you get the hang of it. After processing, you would need to etch the board and I strongly recommend Seno GS Etch in a Bag for PCB production.

Plenty of help is available from readers on the EPE Chat Zone *forum at:* **www.chatzones.co.uk**.

Magnetic amplifier

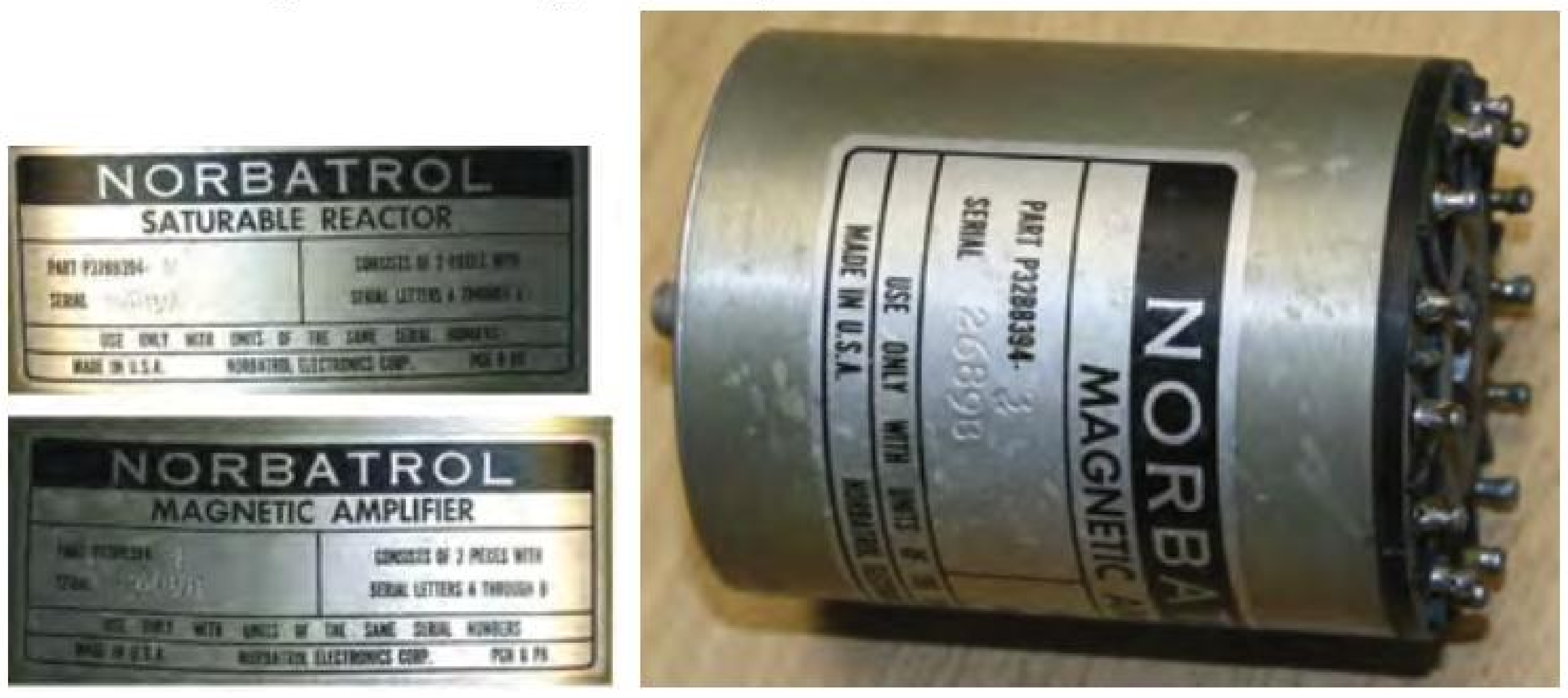
Dear editor
I enjoyed the magnetic amplifier piece in Mark Nelson's *Techno Talk* column (*EPE*, March 2016). Here's a photo of a magnetic amplifier in my Aircraft Museum, along with its corresponding saturable reactor (externally same appearance) They were recovered from a scrapped VC-10 aircraft.

Photographing the curved labels was an interesting challenge. I rolled the devices along the scanner bed while trying to keep pace with the moving imaging carriage!

I wish I had some information on the way this equipment operated – perhaps the photos will jog the memory of an *EPE* reader?

Godfrey Manning G4GLM, Edgware

Matt Pulzer replies:
Fascinating technology – many thanks.



Max's Cool Beans

By Max The Magnificent

Cunning coding tips and tricks – Part 3

As you've probably noticed, I've been bouncing back and forth between my *Cool Beans* and *Hot Beans* columns for the past few months. This means there's been a bit of a gap since my previous ramblings on this topic. So, just to make sure we're all tap-dancing to the same drum beat, let's remind ourselves that a lot of my projects boast rings of tri-colored LEDs (check out my *Cunning Chronograph Has It's Freak On* video at: **http://bit.ly/1QmDUlc**). In particular, I'm using NeoPixels, which are Adafruit's presentation of Worldsemi's WS2812 devices (see my *EPE* columns July, August, and October 2015).

Each NeoPixel (WS2812) is a 5mm × 5mm (2mm deep) package containing super-bright red, green, and blue LEDs, each with its own 8-bit PWM controller. The really clever part is that each package has only four pins: 5V, 0V (GND), Data-In, and Data-Out, which means you can daisy chain NeoPixels together. In practice, you can control hundreds of NeoPixels using a single pin on your microcontroller (for the purpose of these discussions, we'll assume we're playing with an Arduino Uno microcontroller development board).

Out-tricking the trickster

In Part 1 of this series (*EPE*, January 2016), we started by assuming we were working with an 8-pixel ring called (a tad simplistically) `ring`. We can think of this as being as an 8-element array (`ring[0]` to `ring[7]`) stored in the Arduino's memory. Each of these elements is comprised of three 8-bit values, which are used to store that pixel's red, green, and blue (RGB) values. The `setPixelColor(i,R,G,B)` function is used to specify (ie, load the array with) the RGB values associated with pixel `i`. Meanwhile, the `show()` function is used to stream the entire contents of the array out into the chain of NeoPixels, which are presented as a ring in our case.

We then moved on to consider a simple example. Our goal was to have a single red pixel racing clockwise around the ring. In order to do this, we need to turn one pixel on and turn the previous pixel off. We started by imagining what would happen if we were to call the following snippet of code over and over again:

```
for (i = 0, i < 8; i++) {
   ring.setPixelColor(i,255,0,0);
   ring.setPixelColor((i-1),0,0,0);
   ring.show();
   delay(100);
}
```

As we see, each time round the loop, we first turn pixel `i` on and then turn pixel `(i – 1)` off. We also discussed why this solution won't work for the case where `i` equals 0, and we discussed a cunning solution involving the use of the bitwise AND (&) operator.

Now, this is a little embarrassing because I fear I have been out tricked. Reader Don Morris emailed me to say: 'Hi Max, I enjoyed your article in *EPE*, January 2016. An alternative to the use of binary operations would be to turn the pixel off at the end of the loop before incrementing the counter.' Don included an example code snippet as follows:

```
for(i = 0; i < 8; i++)
{
   ring.setPixelColor(i, 255, 0, 0);
   ring.show();
   delay(100);
   ring.setPixelColor(i, 0, 0, 0);
}
```

We'll, blow me down, he's right. This illustrates one of the things I love about computers – both hardware (logic) and software – there are always so many different ways of doing things.

In Part 2 of this series (*EPE*, March 2016) we noted that my bit-wise AND approach only works when you are playing with rings that have 2^n elements (eg, 2^2 = 4, 2^3 = 8, and 2^4 = 16), but that it falls over with rings that don't contain 2^n elements. My solution was to use cross-reference arrays. Much to my chagrin, I note that Don's solution also covers non-2^n rings. On the bright side, my cross-reference arrays also address things like miss-aligning the rings. The bottom line is that, the next time I do something like this, I will use a combination of my cross-reference arrays with Don's cunning coding trick.

Increasingly sophisticated scenarios

Everything we've discussed thus far involved a single pixel at full brightness racing around the ring. In turn, this involved turning one pixel on and the previous pixel off (or vice versa, in the case of Don's solution). But what happens if we were to have, for example, a 5-element ring and we want to implement a 'fading trail' type effect; perhaps something like the following:

```
for (i = 0, i < 5; i++) {
   ring.setPixelColor(i,255,0,0);
   ring.setPixelColor((i-1),127,0,0);
   ring.setPixelColor((i-2),63,0,0);
   ring.setPixelColor((i-3),0,0,0);
   ring.show();
   delay(100);
}
```

In this case, we want to turn the new pixel on at full brightness; set the previous pixel to half brightness; set the pixel before that to quarter brightness; and turn the pixel before that fully off. In this case, neither my bitwise operation nor Don's solution will be of use. My cross-reference tables could handle the task, but only by augmenting them with more and more elements to the extent that they become painfully unwieldy.

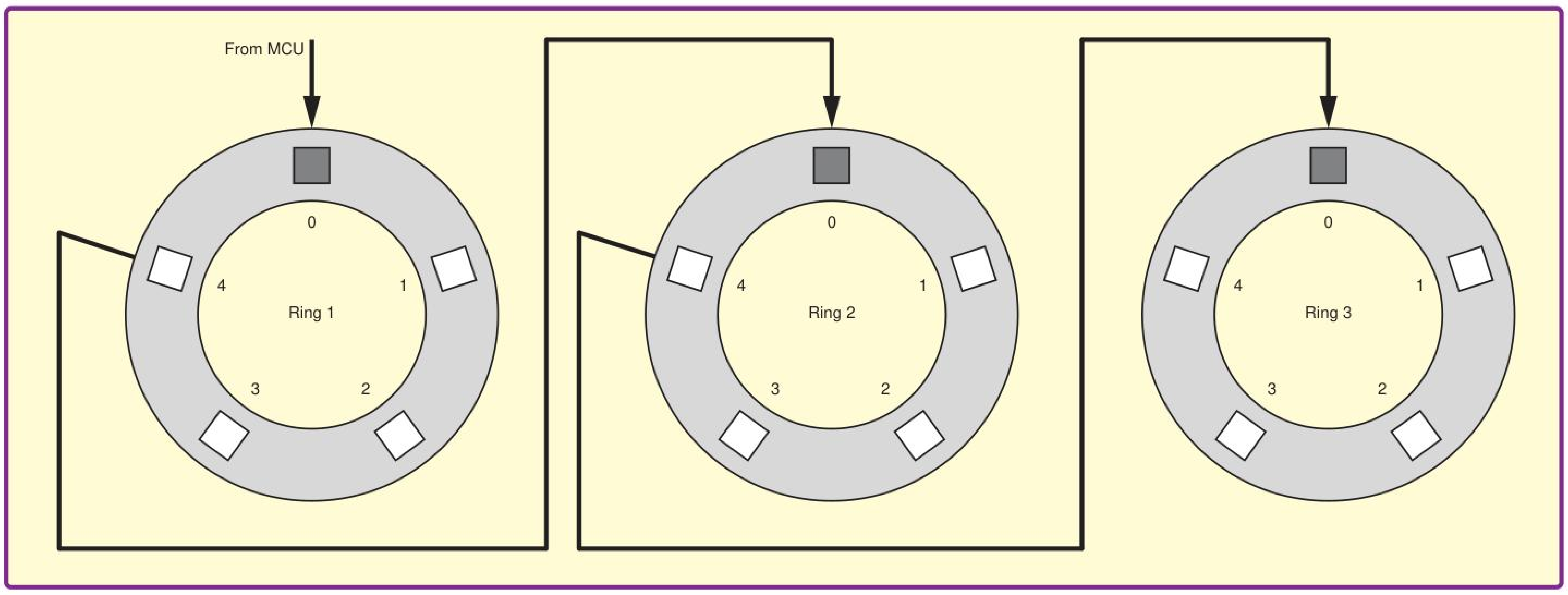


Fig.1. Three 5-element rings daisy-chained together

More rings...

While we're thinking about this, let's 'up the ante' a bit; let's suppose that we have three rings, each containing five elements. The first thing to consider is how we are going to connect these rings to our microcontroller. One option would be to use a separate pin for each ring, but this means we've used three out of our limited number of pins (this would start to become a real problem if we wished to increase the number of rings to say 20 or 30). Another option is to simply daisy-chain the three rings together and to use a single pin to control all three rings, as illustrated in Fig. 1.

Due to the way in which these things are instantiated, declaring a single 15-element array (`rings[0]` to `rings[14]`) as opposed to three 5-element arrays consumes a tad less memory. Furthermore, there is a small overhead involved in initiating the streaming of the pixel data, which means it's a smidgeon faster to perform a single large stream to a 15-element array, as opposed to performing multiple small streams to three 5-element arrays.

Of course, this latter point is only applicable if we always wish to be changing all three rings simultaneously. If we wanted to modify only a single ring at a time, then it would be slightly more efficient to treat each ring as a separate entity. This is one of those 'you pays your money and you makes your choice' type things. Generally speaking, the differences in memory and speed between the two approaches would be of interest only in the most memory-limited and/or timing-critical applications.

Mixing control approaches

So, how are we going to control our three rings? For the sake of providing a simple example, let's assume that we want to have red pixels racing around each ring – that is, all three pixel 0s will be lit, then all three pixel 0s will be turned off and all three pixel 1s will be lit, and so forth. One solution might be to use a combination of my cross-reference arrays with Don's solution. For example, assume we declare three cross-reference arrays as follows:

```
xRef1[5] = {0,1,2,3,4};       // Ring 1
xRef2[5] = {5,6,7,8,9};       // Ring 2
xRef3[5] = {10,11,12,13,14}; // Ring 3
```

Now suppose that we call the following snippet of code over and over again:

```
for(i = 0; i < 5; i++)
{
   ring.setPixelColor(xRef1[i], 255, 0, 0);
   ring.setPixelColor(xRef2[i], 255, 0, 0);
   ring.setPixelColor(xRef3[i], 255, 0, 0);
   ring.show();
   delay(100);
   ring.setPixelColor(xRef1[i], 0, 0, 0);
   ring.setPixelColor(xRef2[i], 0, 0, 0);
   ring.setPixelColor(xRef3[i], 0, 0, 0);
}
```

Pretty snazzy, eh? But what if we wished to implement something like the 'fading trail effect' we discussed above? This is where professional programmers would start to whip all sorts of cunning doodads out of their bags of tricks, like pointers and structures and suchlike.

Now, these are all well and good, but I'm a simple man (many people have told me so). Thus, a solution I've been using recently is based on multidimensional arrays of byte-sized fields, where the type `byte` represents an unsigned 8-bit integer. This is particularly efficacious in the case of an Arduino Uno, which has an 8-bit data bus, and which is therefore very efficient when it comes to performing byte-sized operations.

Let's assume that we create a 15 x 3 array as follows (I'm going to leave you to populate the values associated with Ring 3 to see if you've been paying attention):

```
byte stuff[15][3] = {
   {4,1,0},{0,2,1},{1,3,2},{2,4,3},{3,0,4}, // Ring 1
   {9,6,5},{5,7,6},{6,8,7},{7,9,8},{8,5,9}, // Ring 2
   {?,?,?},{?,?,?},{?,?,?},{?,?,?},{?,?,?}  // Ring 3
};
```

The 15 main elements in this array correspond to our 15 pixels. Each of these elements has an associated triplet. The first value in the triplet can be considered to be a pointer to the main element in this array corresponding to the previous pixel associated with this ring in an anticlockwise direction; the second value in the triplet can be considered to be a pointer to the main element in this array corresponding to the next pixel associated with this ring in a clockwise direction; the third value in the triplet can be considered to be a pointer to the corresponding element in the `rings[]` array (this final value is a little superfluous here, but it becomes useful in more complicated scenarios).

Now let's assume that we have the following definitions, which we will use as index values into our triplets:

```
#define acw 0 // Anticlockwise
#define cw 1  // Clockwise
#define p2r 2 // Pointer into rings[]
```

Now consider the following snippet of code, whose purpose is to send a single red pixel racing around Ring 2.

```
byte i = 5;    // First element in Ring 2

do
{
   ring.setPixelColor(stuff[i][p2r], 255, 0, 0);
   ring.show();

   delay(100);
   ring.setPixelColor(stuff[i][p2r], 0, 0, 0);

   i = stuff[i][cw];   // Move to next element

} while (1);           // Do this forever
```

Now that I look at this, I'm afraid that it might be a little cryptic (it's an artificial example taken out of context), but it's not so bad once you've wrapped your brain around it. As we see, we no longer have to worry about `for ()` loops and end conditions, because each main element in our array points to the next elements clockwise and anticlockwise associated with that ring.

The main thing is that by using this approach we can now implement all sorts of clever effects. For example, our fading trail; we could implement this as follows:

```
byte i = 5;            // First element in Ring 2
byte f;                // Used for fade

do
{
   ring.setPixelColor(stuff[i][p2r], 255, 0, 0);
   f = stuff[i][acw];
   ring.setPixelColor(stuff[f][p2r], 127, 0, 0);
   f = stuff[f][acw];
   ring.setPixelColor(stuff[f][p2r], 63, 0, 0);
   f = stuff[f][acw];
   ring.setPixelColor(stuff[f][p2r], 0, 0, 0);

   ring.show();
   delay(100);
   i = stuff[i][cw];   // Move to next element

} while (1);           // Do this forever
```

As you gain familiarity with this technique, you'll discover that the more complex the effect you are trying to achieve, the more efficacious this approach becomes.

Next month

In June, we'll start a new topic. We'll still be using NeoPixels, but not in a ring – instead we'll be using a bunch of them to replicate the randomly flickering flames of a minature campfire. Until then, have a good one!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

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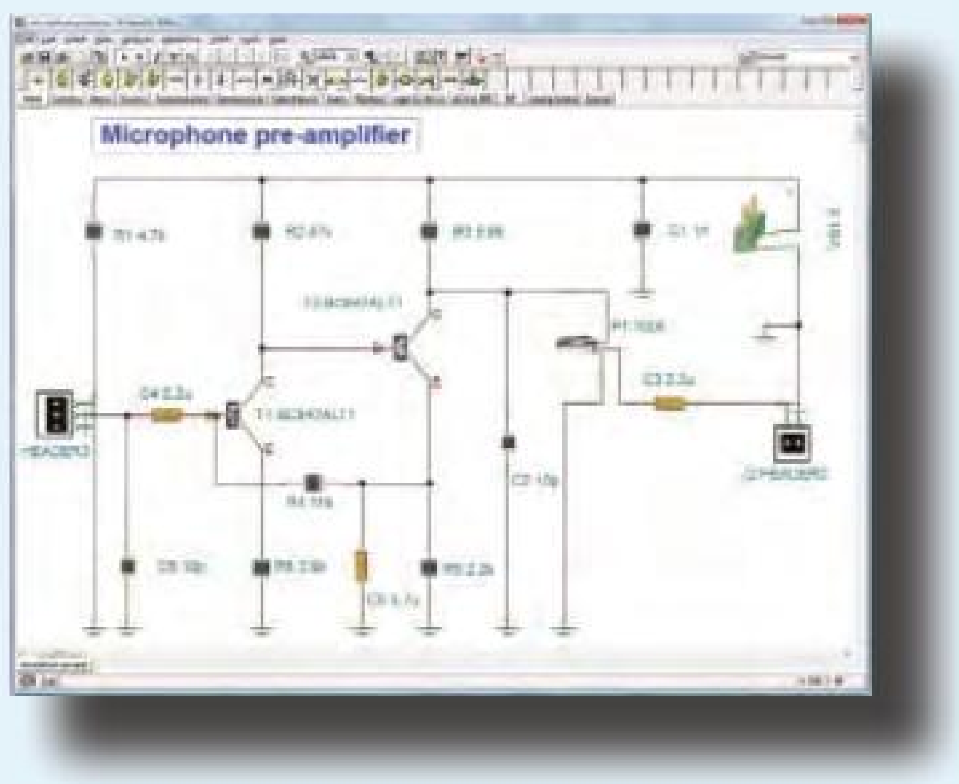

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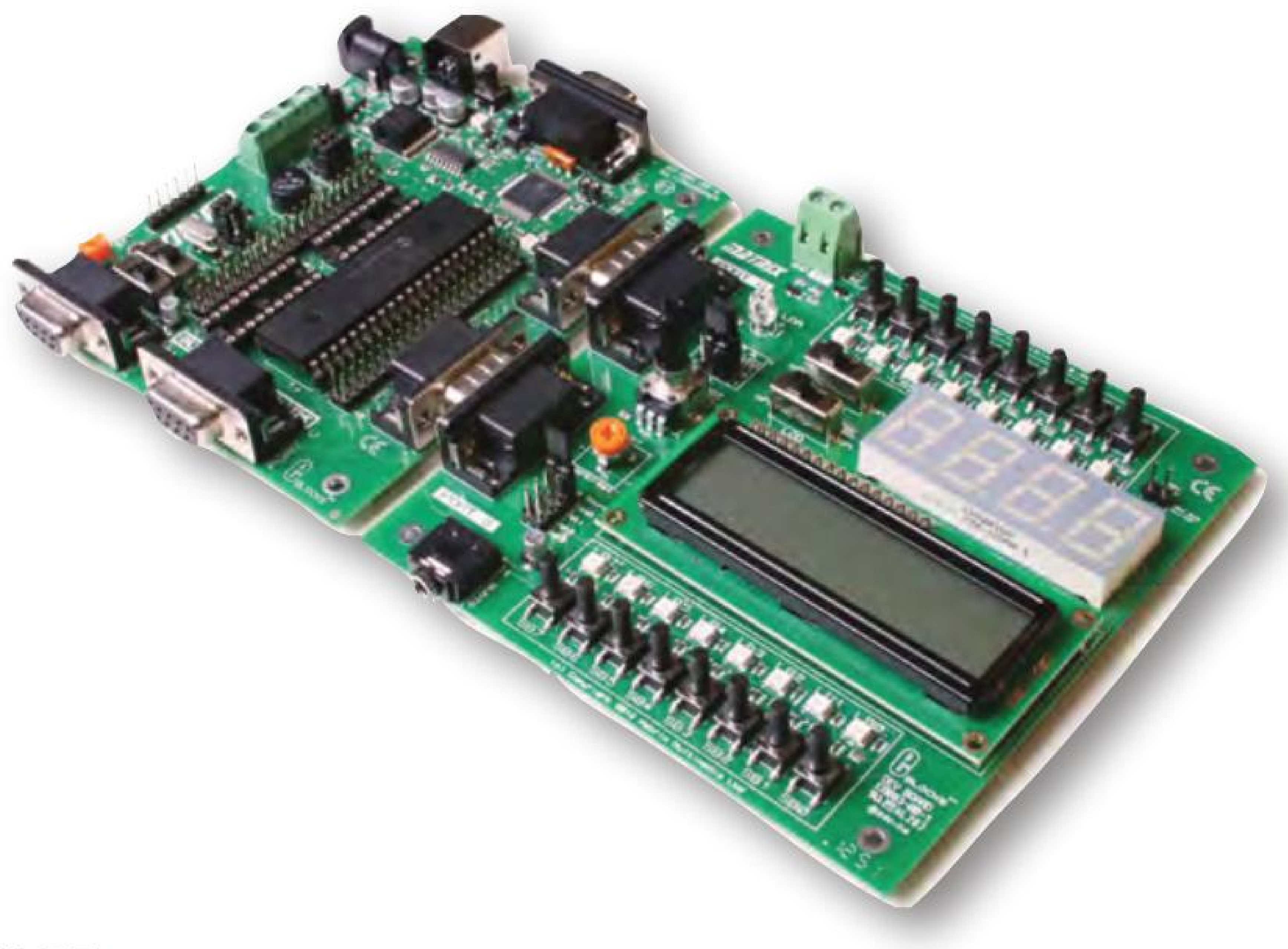

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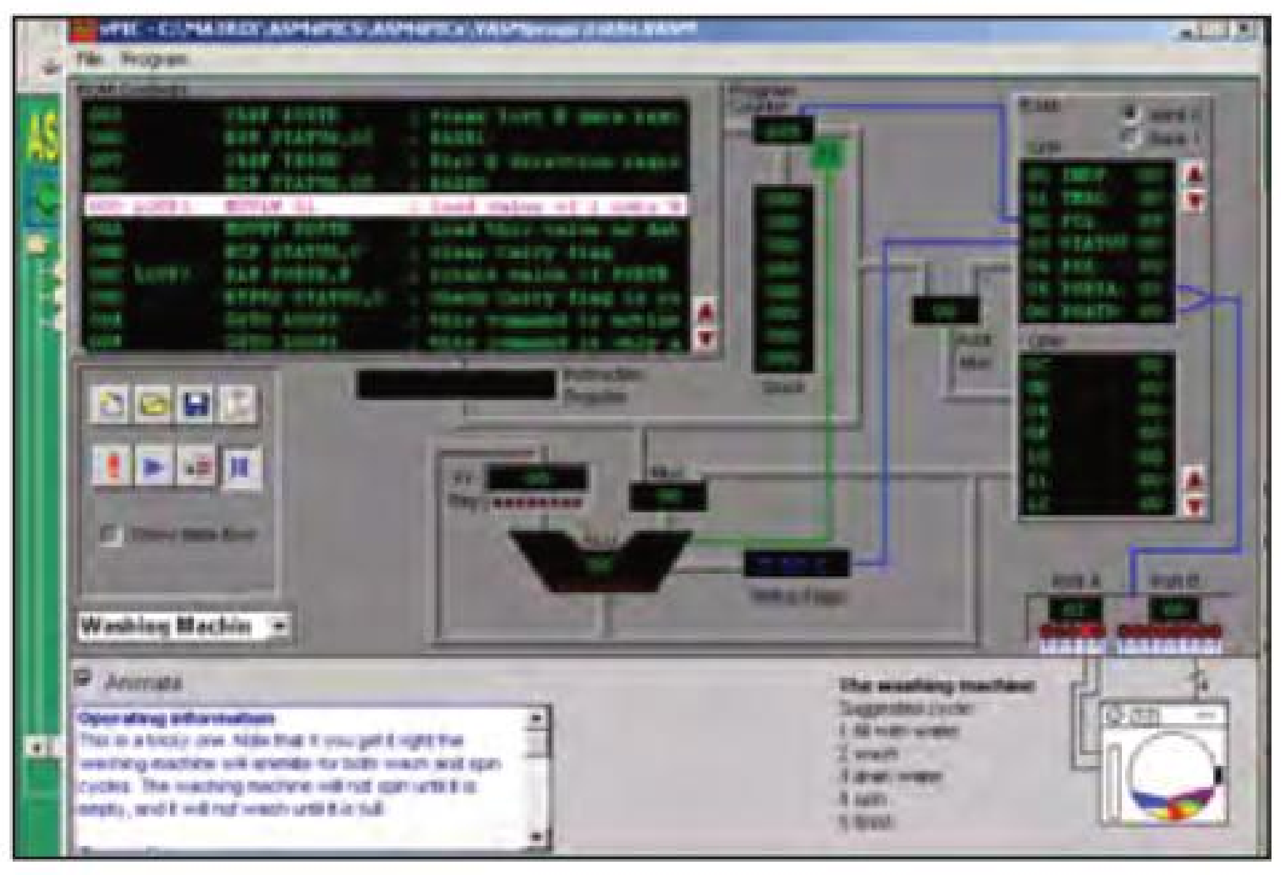

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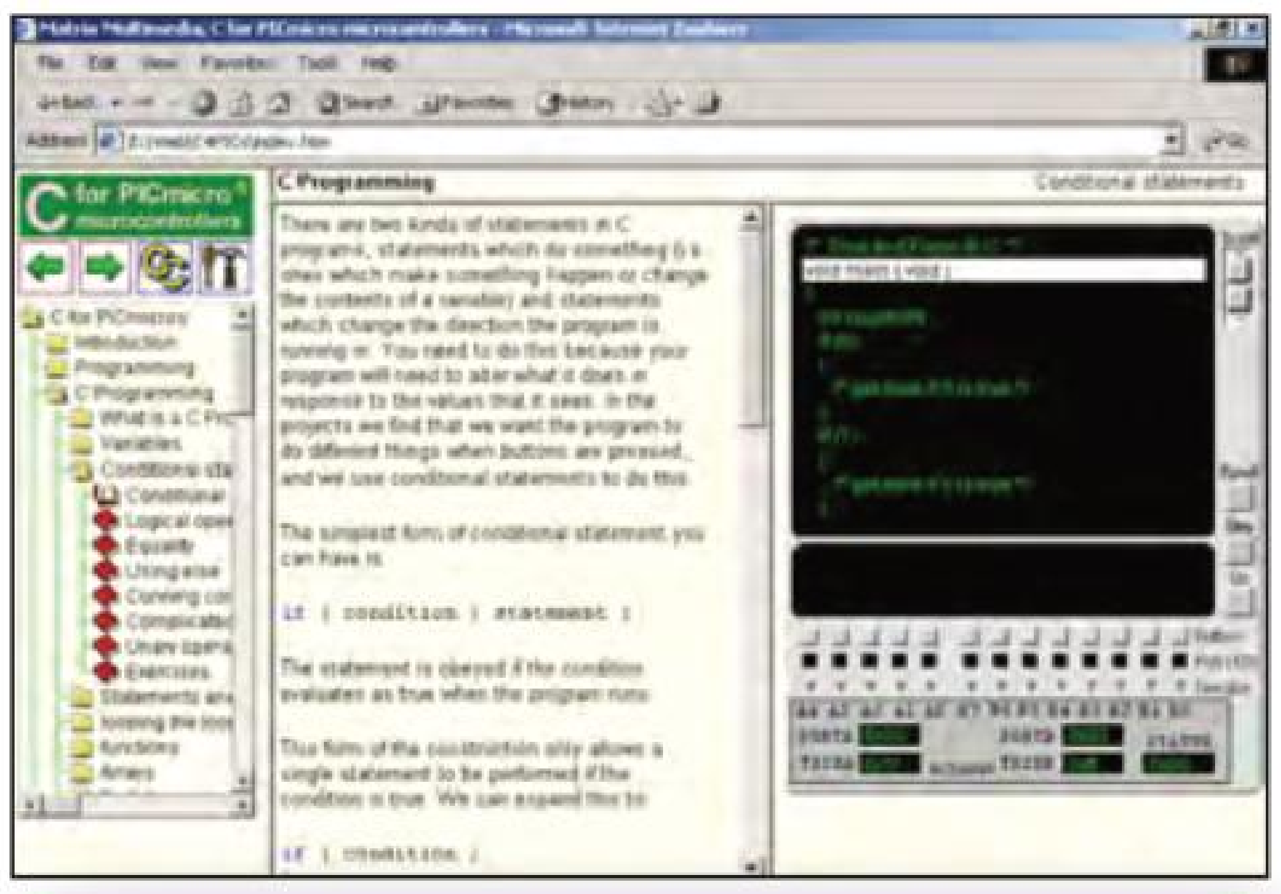

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Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment displays, motor controllers and LCDs. The use of macros allows you to control these devices without getting bogged down in understanding the programming. When used in conjunction with the development board this provides a seamless solution that allows you to program chips in minutes.

- Requires no programming experience
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- Produces ASM code for a range of 18, 28 and 40-pin devices
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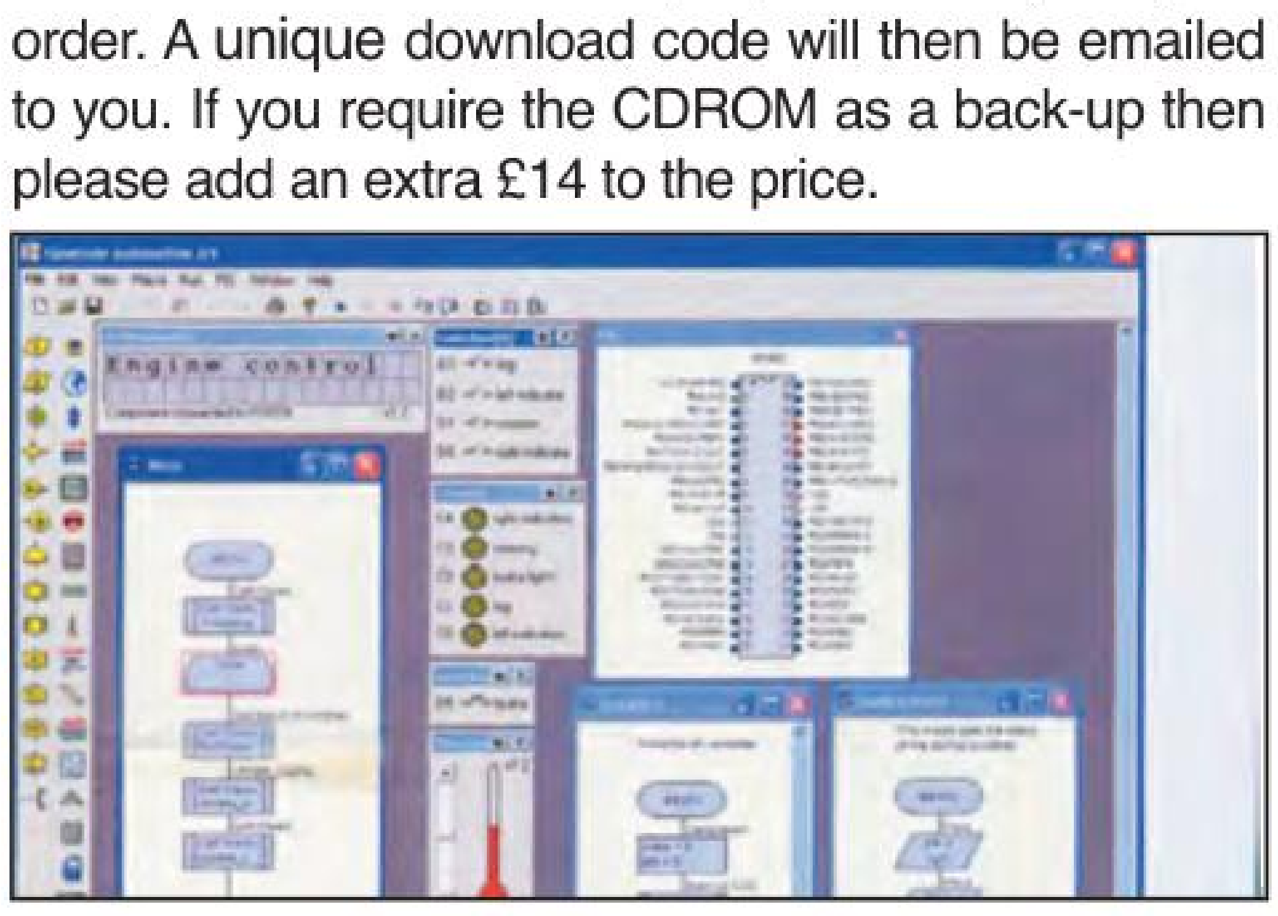
- Pulse width modulation
- I2C.

Please note: Due to popular demand, Flowcode PICmicro, AVR, DSPIC, PIC24 & ARM V6 are now available as a download. Please include your email address and a username (of your choice) on your order. A unique download code will then be emailed to you. If you require the CDROM as a back-up then please add an extra £14 to the price.



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Prices for each of the CD-ROMs above are:

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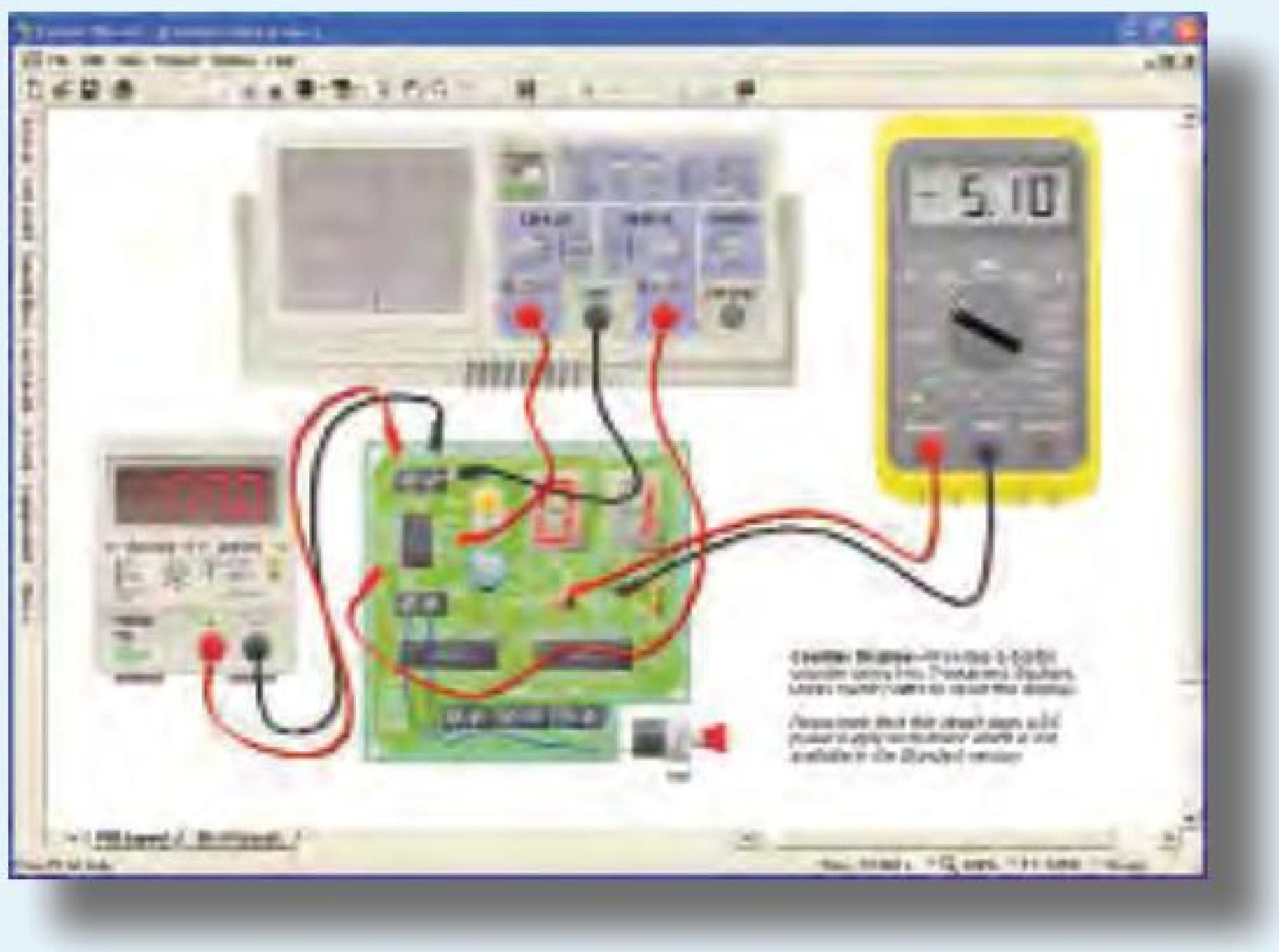

This software can be used with the *Jump Start* and *Teach-In 2011* series (and the *Teach-In 4* book).

Standard **£61.25** inc. VAT. Professional **£75** plus VAT.

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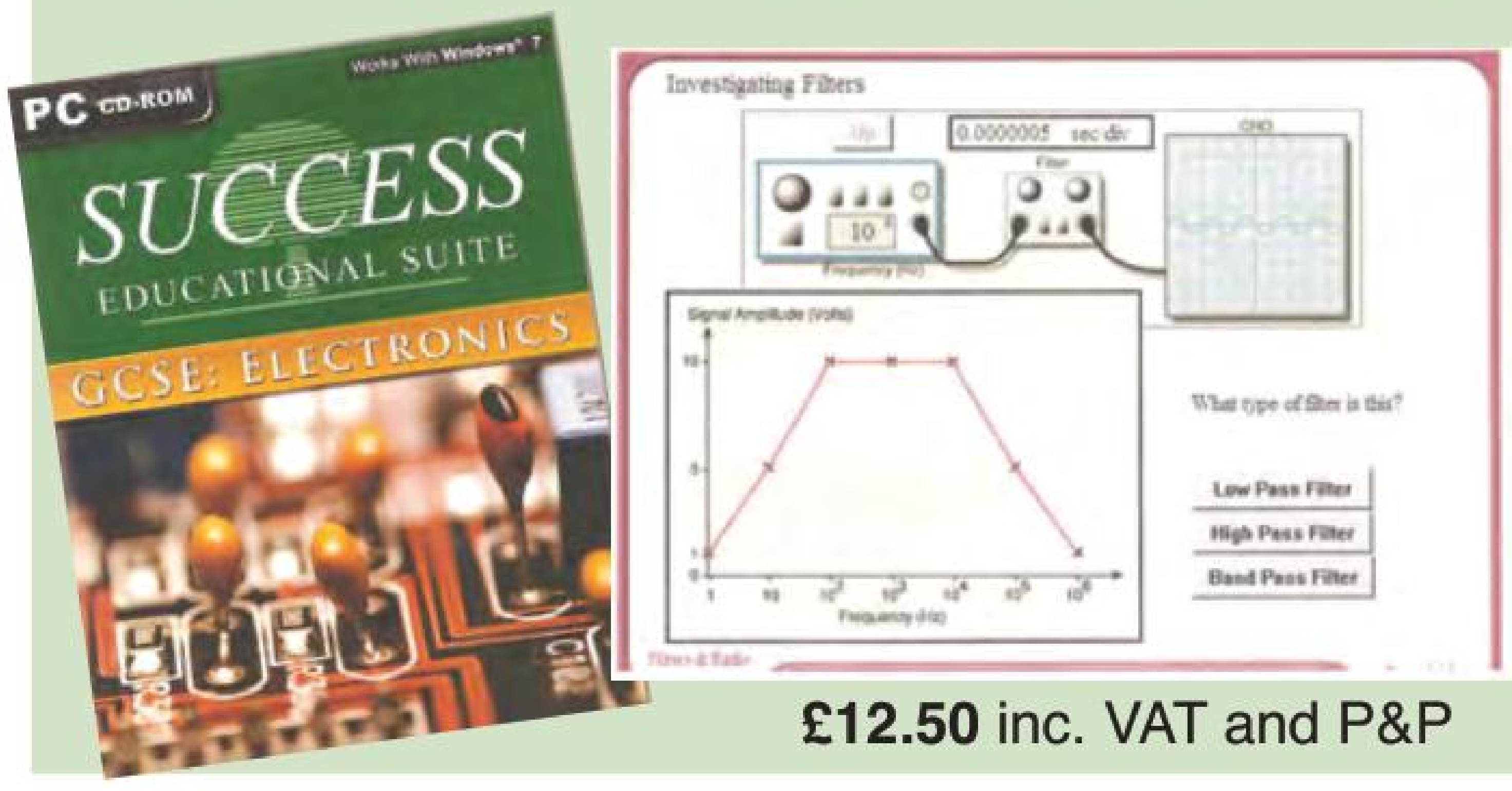

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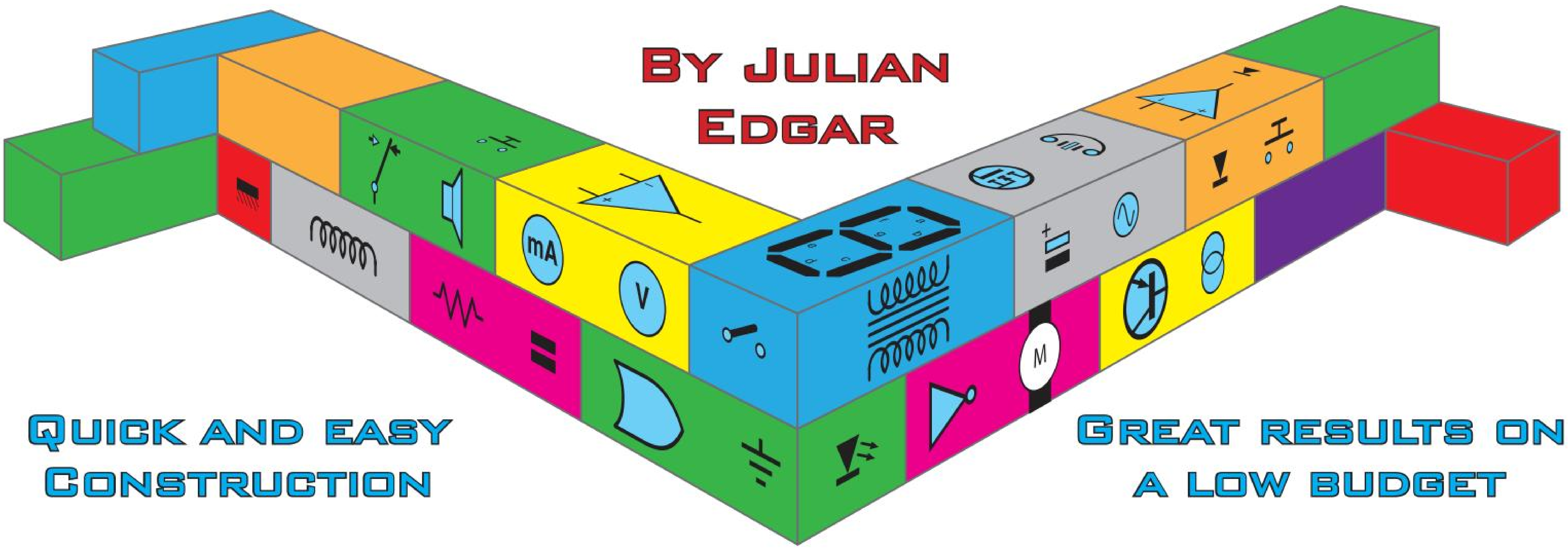


By Julian Edgar

Quick and easy construction

Great results on a low budget

Variable PWM power module

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! These projects range from around £15 to under a fiver... bargains!

Control the brightness of lights and the speed of fans

Here is an absolute beauty – a tiny, efficient and cheap variable pulse-width power module. Hook it up to a DC fan, and you can control the fan speed via the supplied knob. Power filament light bulbs and you can control their brightness, steplessly and without flicker.

And for around £2, delivered to your letterbox, nothing beats this module for value.

Many applications

In fact, this module is so cheap that suddenly uses become viable that would otherwise require less-efficient methods. The cooling fan in your amplifier a bit loud and strong? Once upon a time you'd have placed a dropping resistor in series, wasting power and generating heat. Now you can use this module instead – and, via the knob, you can set the fan speed precisely to give the desired flow. Want the cheapest model train speed controller you'll ever find? Just use a discarded 12V plugpack and one of these modules – perhaps feeding the track in series with a 12V light bulb to give short-circuit protection.

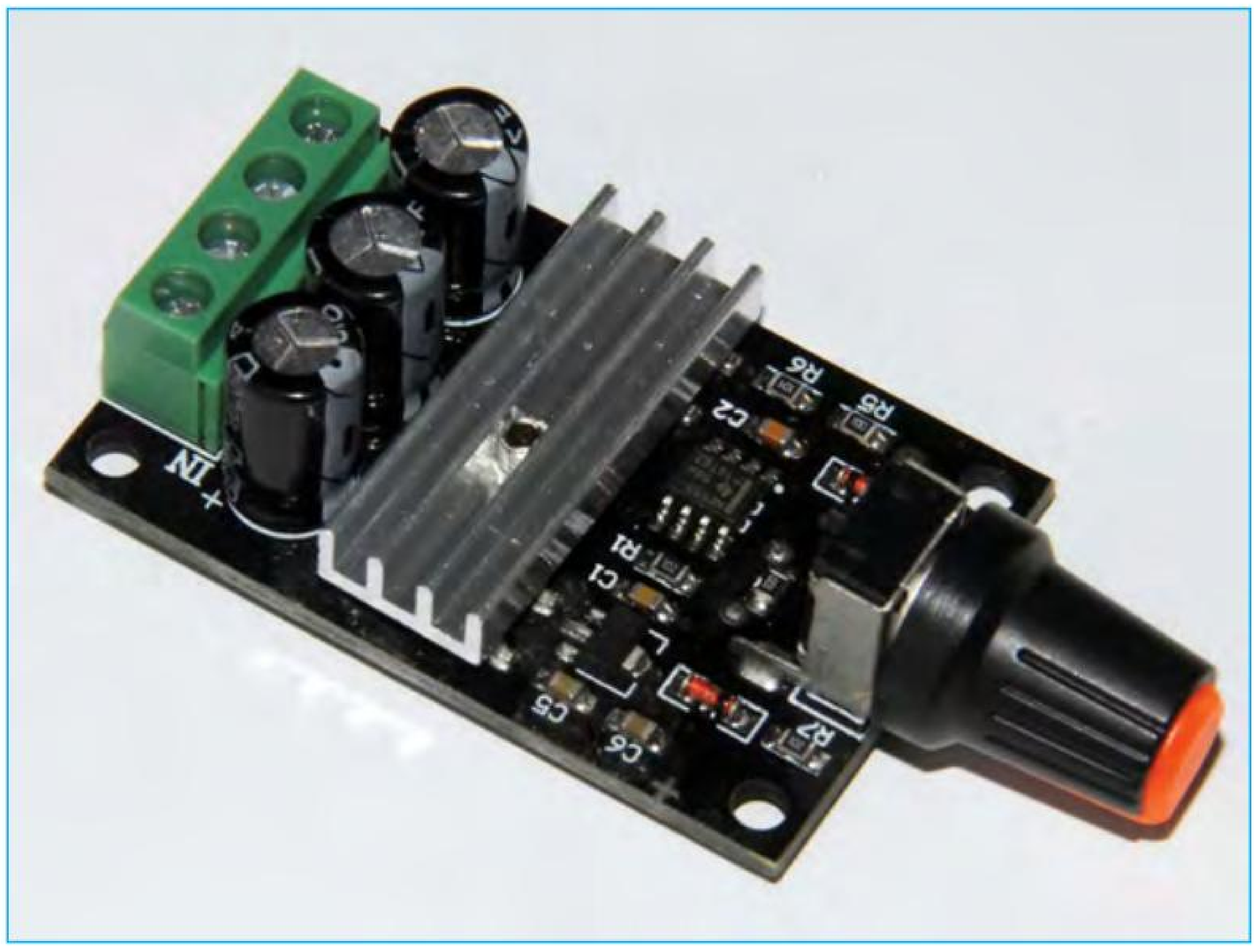


Fig.1. This tiny module is just 51 × 33 × 16mm but can control currents of up to 3A. It's perfect for controlling the speed of fans and other small motors.

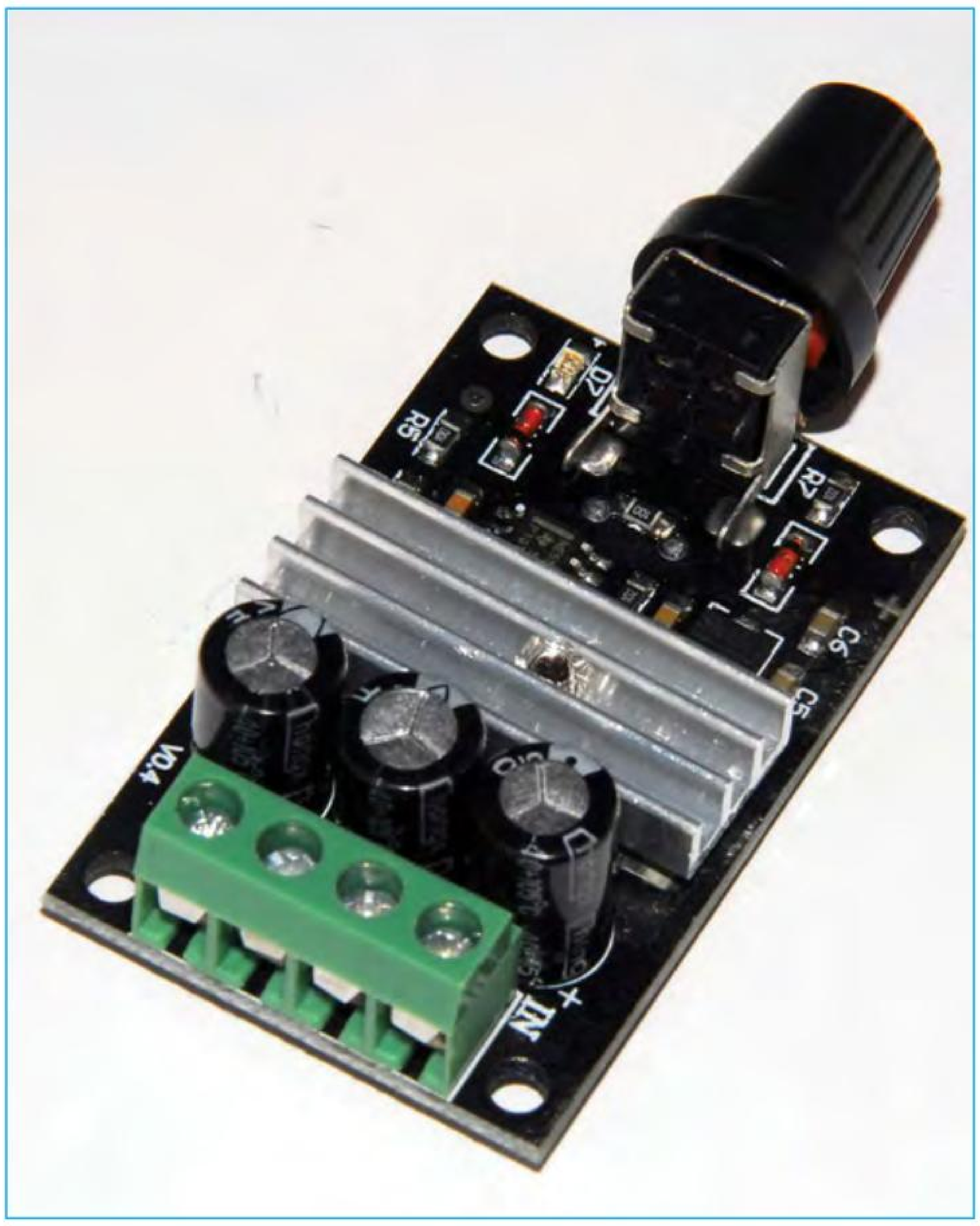


Fig.2. Connections are via a 4-way terminal block positioned at one end. The pictured heat sink is easily unscrewed and replaced with a larger one; however, in our full-load testing the heat sink rose in temperature only about 10ºC.

Ratings

So is the module cheap and nasty? To my surprise, I found it lived up to its specs – in fact, it more than lived up to them!

The module is rated by the maker at 3A; quite a high current considering the board's diminutive dimensions. But in testing I found it's quite happy to run at this maximum current, with the supplied heat sink rising

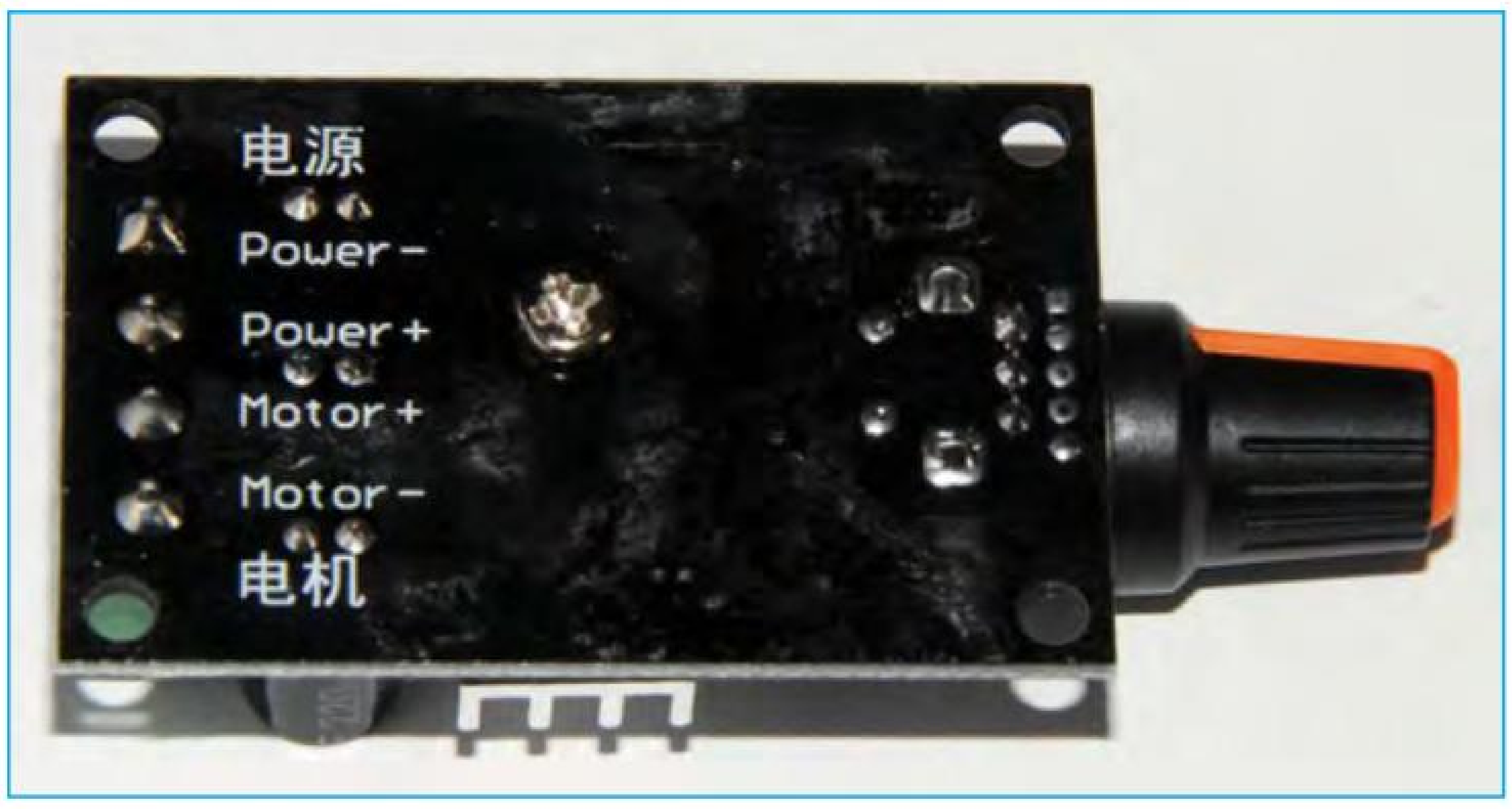


Fig.3. The connections are written on the underside of the board in English, making installation quick and easy.

only about 10ºC above ambient. In fact, I briefly increased current to 4.5A and nothing turned to smoke…

The measured pulse-width modulation frequency is 25kHz. That is, the output signal is turned on and off 25,000 times per second. This is high enough in frequency that motor windings cannot be heard 'singing', and gives good control of small DC motors. The input voltage range is 6 – 28V.

Small, versatile and easy to use

The board is about 51 × 33 × 16mm (L × W × H), with the knob protruding about 19mm. Connections are via a 4-way terminal strip, with the correct connections written on the bottom of the board in English. Four mounting holes are provided.

At this price and with this capability, this might be a situation where it's worthwhile buying half a dozen of the modules and putting them aside for use as and when needed.

Sourcing

At the time of writing, the module can be found at **ebay.co.uk** as item number 400923847572, or just go to: **http://tinyurl.com/jj8wwep**

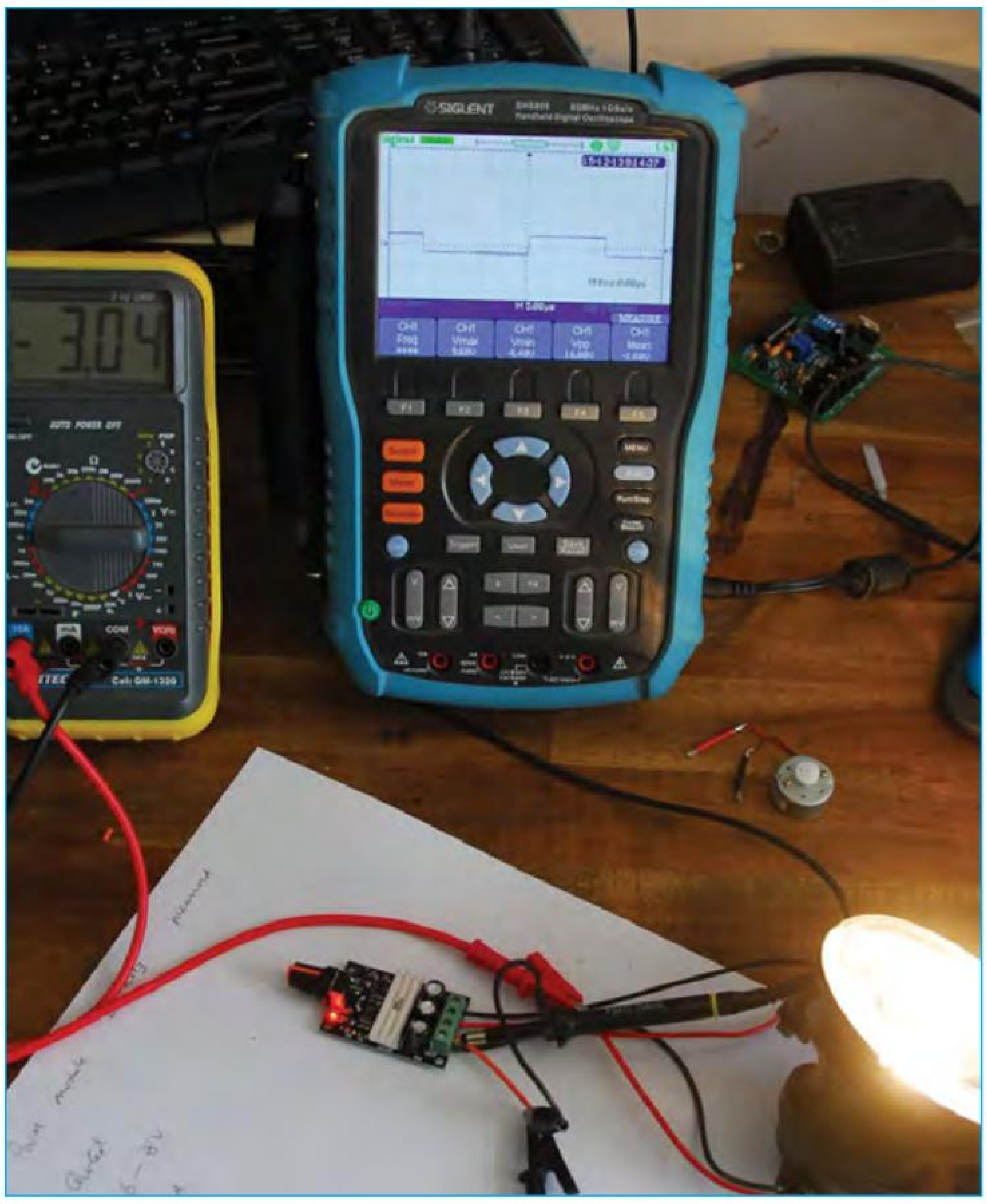
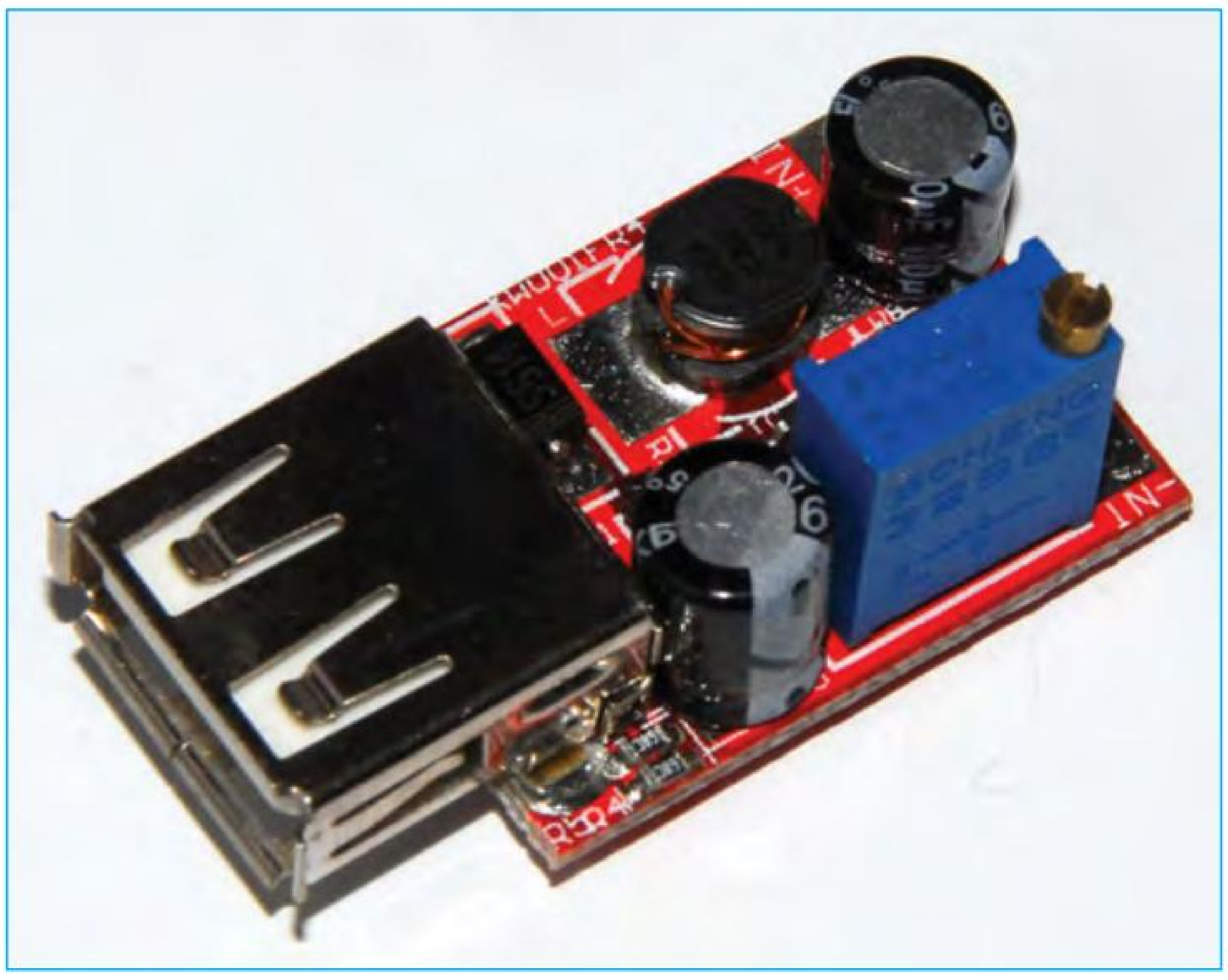


Fig.4. OK, so my workplace isn't the tidiest, but here the module can be seen powering an incandescent light bulb load, running at about 50 per cent duty cycle and with a current of just over 3A.

I also found it by searching under '1203B DC Pulse Width Modulator PWM DC Motor Speed Controller Regulator Switch'. Have a good hunt around for the best price, as the cost does seem to fluctuate a fair bit.

Next month

Here's a cheap module that will provide a charging source for any USB-charged device – a phone, tablet, even a rechargeable torch. The beauty of this device is that it is a boost converter, so it can do this charging while using an input voltage well below 5V.



Next month – a cheap and useful USB Boost Charger

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All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

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ESR ELECTRONIC COMPONENTS 6
HAMMOND ELECTRONICS Ltd 24
iCSAT 53
JPG ELECTRONICS 80
KCS . . . . Cover (iv)
LASER BUSINESS SYSTEMS 22
MICROCHIP . . . . Cover (ii), Cover (iii) & 10
PEAK ELECTRONIC DESIGN 5
PICO TECHNOLOGY 68
POLABS D.O.O. 36
QUASAR ELECTRONICS 2/3
STEWART OF READING 63
TAG-CONNECT 59
WEARDALE ELECTRONICS 77

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Next Month

Content may be subject to change

Audio Signal Injector & Tracer

This *Audio Signal Injector/Tracer* is ideal for troubleshooting AM radio and audio circuits. It comprises a 1kHz oscillator (the *Injector*) and an in-built preamp and amplifier with a headphone jack (the *Tracer*) so you can trace signals right through an amplifier or radio circuit to locate faults.

Infrasound Snooper

Back in March 2014 we published the *Infrasound Detector* for low frequency measurements. Now you can 'listen' to low frequency vibrations with our *Infrasound Snooper*. It frequency shifts and amplitude modulates a frequency range of about 1Hz to 20Hz by about five or six octaves so that you can listen directly to wind turbines or elephants, crocodiles and other animals that communicate with infrasound.

Champion Preamp

You can use this simple unit as a general-purpose stereo preamp or as a dual-channel preamp, with a microphone for one channel and guitar in the other. One channel can have fixed gain, while the other is variable with an on-board trimpot or external potentiometer. Better still, it gives good performance and will work over a wide range of supply voltages.

Teach-In 2016 – Part 5

Next month, we will look at ways in which an Arduino can handle multiple sensors with a limited number of wire connections using the highly versatile 1-wire bus system. Plus, we will introduce file handling and our *Get Real* project will be a versatile standalone monitoring system that can capture large amounts of data, conveniently processing and storing it on a conventional SD memory card.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks*, *PIC n' Mix* and *Net Work*.

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- Volume pricing
- Credit lines
- Long-term orders and scheduling
- Programming and value add services
- Ability to adjust open orders
- Ship to your sites globally
- Online order status and notifications

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KCS TraceME

2G 3G 4G LBS
LoRa(TM) BLE M2M
Iridium Sensor
LoRa
Bluetooth(R)
SMS
iBeacon(TM)
Glonass GPRS
RF GPS
Internet of Things
SOS

QUECTEL
M95 M95FA-03-STD M95FAR01A01
FA
S2-W2042
SN:MP24912N4000189
IMEI:863071016649037
CE2200
L76-M33
L76NR03A01-K

LoRa ™ Internet of Things

KCS has extended their successful TraceME product line with an advanced module, targeted for worldwide mobility in the Internet of Things era. The latest development of the TraceME GPS/GPRS Track and Trace module will combine the RF location based positioning solution with the LoRa™ technology. This combination offers 'smart objects' being even smarter, since LoRa™ enables long range, battery friendly communication in a wide variety of (M2M) applications. Supporting GPRS/SMS and optional 3G, Wi-Fi, Bluetooth LE, ANT/ANT+ and iBeacon™ provides easy integration with existing wireless networks and mobile apps. Other variants in the high/mid-range and budget-line will follow soon.

ANTI-THEFT module based on RF

KCS TraceME product line offers an intelligent location based positioning solution for indoor and anti-theft applications.The solution is based on RF with an intelligent algorithm of measuring the propagation time of transmitted (proprietary protocol) signals. Unique features are: minimum size (46x21x6.5mm), weight (7 grams for fully equipped PCB) and a standby battery lifespan of more than 10 years.'Listen before talk' algorithm makes it practically impossible to locate the module, which secures the valuable vehicle or asset. Supporting GPRS/SMS and optional 3G, Wi-Fi, Bluetooth LE, ANT/ANT+ and iBeacon provide easy integration with existing wireless networks and mobile apps.

www.Trace.ME

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